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**QUARTERLY TECHNICAL PROGRESS REPORT
FOR THE DEVELOPMENT
OF A COAL-FIRED COMBUSTION SYSTEM FOR
INDUSTRIAL PROCESS HEATING APPLICATIONS**

CONTRACT DE-AC22-91PC91161

JANUARY 1994 - MARCH 1994

PREPARED FOR

**U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER**

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1.0 EXECUTIVE SUMMARY

PETC has implemented a number of advanced combustion research projects that will lead to the establishment of a broad, commercially acceptable engineering data base for the advancement of coal as the fuel of choice for boilers, furnaces, and process heaters. Vortec Corporation's Phase III development contract DE-AC22-91PC91161 for a "Coal-Fired Combustion System for Industrial Process Heating Applications" is a project funded under the DOE/PETC advanced combustion program.

This advanced combustion system research program is for the development of innovative coal-fired process heaters which can be used for high temperature melting, smelting and waste vitrification processes. The process heater systems to be developed have multiple use applications; however, the Phase III research effort is being focused on the development of a process heater system to be used for producing value added vitrified glass products from boiler/incinerator ashes and industrial wastes. The primary objective of the Phase III project is to develop and integrate all the system components, from fuel through total system controls, and then test the complete system in order to evaluate its potential marketability.

The past quarter began with a two-day test performed in January to determine the cause of pulsations in the batch feed system observed during pilot-scale testing of surrogate TSCA incinerator ash performed in December of 1993. Two different batch feedstocks were used during this test: flyash and cullet. The cause of the pulsations was traced to a worn part in the feeder located at the bottom of the batch feed tank. The problem was corrected by replacing the worn part with the corresponding part on the existing coal feed tank. A new feeder for the existing coal tank, which had previously been ordered as part of the new coal handling system, was procured and installed.

The data from the pilot-scale tests performed on surrogate TSCA incinerator ash during December of 1993 was collected and analyzed. All samples which required chemical analysis were sent to the appropriate independent laboratory, and the resulting analyses were collected. All of the glass produced during the test passed both the Toxicity Characteristics Leach Procedure (TCLP) and the Product Consistency Test (PCT) by approximately two orders of magnitude. The data was also analyzed to determine the partitioning of the surrogate heavy metals and simulated radionuclides among the effluent

streams. A draft test report was written based on the data and analyses performed to date. The test report will be released in final form after some additional analyses are performed.

Additional modifications were performed to the pilot-scale CMS housed at UPARC. A spool-piece extension was added to the CRV combustor to increase the residence time in the combustor. The CRV combustor and cyclone melter were both relined with new refractory. The precombustors were removed from the system, and the flame safety system was reworked to improve reliability.

2.0 INTRODUCTION/BACKGROUND

2.1 Introduction

The Pittsburgh Energy Technology Center (PETC) of the U.S. Department of Energy awarded Vortec Corporation this Phase III contract (No. DE-AC22-91PC91161) for the development of "A Coal-Fired Combustion System for Industrial Process Heating Applications". The effective contract start date was September 3, 1991. The contract period of performance is 36 months. The program established by this contract is described below.

2.2 Background

PETC has implemented a number of advanced combustion research projects that will lead to the establishment of a broad, commercially acceptable engineering data base for the advancement of coal as the fuel of choice for boilers, furnaces, and process heaters. This includes new installations and those existing installations that were originally designed for oil or gas firing. The data generated by these projects must be sufficient for private-sector decisions on the feasibility of using coal as the fuel of choice. This work should also provide incentives for the private sector to continue and expand the development, demonstration, and application of these combustion systems. Vortec Corporation's Coal-Fired Combustion System for Industrial Process Heating Applications is being developed under contract DE-AC22-91PC91161 as part of this DOE development program. The current contract represents the third phase of a three-phase development program. Phase I of the program addressed the technical and economic feasibility of the process, and was initiated in 1987 and completed 1989. Phase II was initiated in 1989 and completed in 1990. During Phase II of the development, design improvements were made to critical components and the test program addressed the performance of the process using several different feedstocks. Phase III of the program was initiated September 1991 and is scheduled for completion in 1994. The Phase III research effort is being focused on the development of a process heater system to be used for producing value-added vitrified glass products from boiler/incinerator ashes and selected industrial wastes.

This coal-fired process heater system is unique in several important aspects. The important advantages of the technology are as follows:

1. Significantly lower capital cost as compared to conventional gas/oil-fired and electric furnaces.
2. Substantially higher thermal efficiency as compared to conventional gas/oil-fired melting furnaces.
3. Satisfaction of projected future emission requirements for NO_x, SO_x and particulates.
4. The process heater system has a degree of operational flexibility unmatched by conventional fossil fuel fired glass melting or mineral wool systems. Several of the unique operational capabilities of this innovative technology include: multi-fuel use capability (including coal, coal slurry, petro-coke, oil and gas), rapid product changeover, and rapid startup/shutdown.

The primary components of the CMS are a counter-rotating suspension preheater and a cyclone melter. An artist rendering of the basic CMS concept is shown in Figure 2.2-1.

Coal combustion and in-flight suspension preheating of the batch ingredients take place in a counter-rotating vortex (CRV) combustion preheater. The ash and other feedstock materials are introduced into the CRV preheater through an injector assembly and are rapidly heated in the flame zone. Any unburned carbonaceous materials are rapidly volatilized and incinerated. The inert materials are heated to nominally 2200°F to 2900°F, depending on the feedstocks utilized, prior to entering the cyclone melter. Combustion air preheated to nominally 1000°F to 1400°F is used in the process. Therefore, high local flame temperatures (>4000°F) are achieved in the CRV preheater. However, NO_x emissions have been demonstrated in the pilot scale CMS to be low; typically less than 200 ppm.

Rapid temperature quenching of the combustion products by the inert waste glass particles and staged combustion provide an effective means of limiting NO_x emissions. The system also has the capability of utilizing natural gas reburning for additional NO_x control. The rapid temperature quenching and the staged combustion which occurs within the CMS are perceived to be the primary controlling mechanisms for reduced NO_x emissions. Experimental data obtained during the course of feasibility experiments with the pilot-scale

Figure 2.2-1. Artist Rendering of Basic CMS

CMS indicate NO_x emissions are lower than the California emission standards (4.5 lbs per ton of glass produced) for glass melting furnaces. In this regard, it should be noted that the California glass melting emission standards for NO_x are currently the most stringent in the United States.

The use of low sulfur or beneficiated coals is the initial approach for the control of SO_x emissions. However, since sodium containing compounds and limestone are ingredients used as fluxes for melting the incinerator ash, there are demonstrated reductions of SO_x emissions from the combustion of medium or high sulfur coals in the recycling system by sodium or limestone injection. The sulfates formed can be effectively removed by an electrostatic precipitator, bag house, or flue gas scrubber. Residual SO₂ or HCl emissions can be reduced using commercially available downstream acid gas scrubbers.

The preheated solid materials from the CRV preheater enter the cyclone melter where they are distributed to the chamber walls by 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 1000°F to 1400°F delivered air preheat capability.

The particulate removal/stack assembly quenches the flue gas temperature exiting the radiation recuperator to 700-750°F by use of a water quench or air dilution system. Commercially available particulate control devices are incorporated into the design as dictated by local environmental regulations. The uncontrolled particulate emission levels of the CMS are about the same as conventional gas-fired glass melting furnaces. Therefore, the use of commercially available particulate control devices will be incorporated into the design as dictated by local flue gas emission regulations. Pilot plant testing to date indicates that a venturi scrubber will be suitable for some applications; however, wet or dry electrostatic precipitators may be necessary to achieve higher levels of particulate emissions control.

A process diagram of a Vortec CMS-based commercial ash vitrification and recycling system is shown in Figure 2.2-2. The basic elements of a commercial ash vitrification and recycling system include:

1. The Vortec multifuel-capable Combustion and Melting System (CMS), consisting of a counter-rotating vortex (CRV) combustor and a 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;
6. a flue gas conditioning/distribution assembly; and
7. a particulate removal/stack assembly.

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Figure 2.2-2. Vortec Ash Vitrification And Recycling System

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, and oil. In some coal-fired applications, pulverized coal can be injected and burned directly in the counter-rotating vortex (CRV) preheater. In other coal-fired applications, the use of a pulverized coal precombustor is advantageous.

Boiler or incinerator ash is delivered to storage bins located within the processing facility. Additives required to produce a suitable product are stored in separate storage bins. The ash and additives are mixed on a batch basis and stored in a feedstock storage bin. The feedstock is then delivered via pneumatic transport or other means to the CMS. Pulverized coal, when used as the primary fuel, is delivered to the process facility in pneumatic transport vehicles and stored in a storage bin. The coal is then delivered via pneumatic transport to the CMS.

2.3 Objectives

This contract is the third phase of a three-phase R&D program which was initiated during March 1987. The objective of the program is to develop an advanced industrial process heater capable of using pulverized coal or coal-derived fuels as the primary fuel.

The objective of Phase I of the program was to verify the technical feasibility and economic benefits of Vortec's advanced Combustion and Melting System (CMS) technology using coal as the fuel of choice. Phase I consisted of two segments, Phase I-A and Phase I-B. During Phase I-A, detailed designs of a proof-of-concept scale coal-fired CMS and the supporting test facilities were completed. It also included tradeoff studies and techno-economic studies to cost optimize the advanced process heater and to evaluate the technical and economic feasibility of the process heater system. In Phase I-B of the program, critical components were tested to validate the feasibility of the Vortec process heater for glass melting with coal as the primary fuel. This phase involved the fabrication, installation and operation of a 3 to 5 x 10⁶ Btu/hr coal-fired CMS test loop at Vortec's high temperature process test facility in Harmarville, PA. Glass melting with 100% coal firing was effectively demonstrated with minimal contamination effects. Glass cullet was the primary process feedstock during the Phase I test program. A conceptual design of a commercial scale CMS glass melter was also developed and techno-economic studies were continued.

The primary objective of the Phase II effort was to improve the performance of the primary components and demonstrate the effective operation of a subscale process heater system integrated with a glass separator/reservoir. The impact of coal ash on glass production quality was assessed and the melting of more complex glasses was evaluated during this phase. Additionally, due to Vortec's commitment to commercialize the process heater technology it is developing with DOE's support, we have analyzed several different markets, particularly in the areas of waste material recycling, in which the Vortec process heater system will offer unique technical and cost advantages. Some preliminary testing was performed using Vortec's pilot scale test system to demonstrate the feasibility of application of the Vortec process heater to these markets with encouraging results.

The primary objective of the Phase III project is to develop and integrate all the system components, from fuel through total system controls, and then test the complete system in order to evaluate its potential marketability. Vortec's primary target market for Phase III is boiler/incinerator ash vitrification. A secondary market application is the oxidation/vitrification of waste glass materials into glass frits which can be recycled into existing glass furnace operations. Potential end uses of the glass products include: mineral fiber manufacturing, glass frits, and aggregates. The glass frits produced can be used as filler for road base asphalt, granules for asphalt shingles and filler for bricks and concrete blocks. Aggregates can also be produced for landscaping and backfill applications.

3.0 PROJECT DESCRIPTION

3.1 Program Description

To accomplish objectives outlined in Section 2.3, Vortec will supply all the necessary personnel, facilities, materials, and services to execute the tasks in the contract Statement of Work. The program is divided into seven (7) technical tasks and a program management task distributed over 36 months as shown in Figure 3.1-1. The tasks in the contract's Statement of Work are provided below in Table 3.1-1.

DOE F 1332.3 (11/84)		U.S. DEPARTMENT OF ENERGY MILESTONE SCHEDULE ☐ PLAN ☒ STATUS REPORT		FORM APPROVED OMB NO. 1801-1400																												
1. TITLE A Coal-Fired Combustion System For Industrial Heating Applications		2. REPORTING PERIOD 1/1/84-3/31/94		3. IDENTIFICATION NUMBER DE-AC22-91PC91161																												
4. PARTICIPANT NAME AND ADDRESS VORTEC CORPORATION 3770 RIDGE PIKE COLLEGEVILLE, PA 19426		5. START DATE 9/3/91		6. COMPLETION DATE 9/3/94																												
7. ELEMENT CODE	8. REPORT-ING ELEMENT	9. DURATION	FY 94				FY				FY				FY				10. PERCENT COMPLETE													
			O	N	D	J	F	M	A	M	J	J	A	S	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4									plan	actual
1.0	Design, Fab. & Inst. Comp. Component Design																															
1.1	Component Design																															
1.2	Component Fabrication																															
1.3	Component Integration																															
2.0	Prelim. System Tests																															
2.1	Test Plan																															
2.2	System Tests																															
3.0	Proof-of-Concept Tests																															
4.0	Economic/Comm. Plan																															
4.1	Economic Evaluation																															
4.2	Commercialization Plan																															
5.0	Conduct Site Demonstration																															
5.1	Demonstration Plan																															
5.2	Site Demonstration																															
6.0	Decommission Facility																															
7.0	Program Manag. & Reporting																															
8.0	TSCA Ash Testing																															
11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE																																

Figure 3.1-1. Phase III Program Schedule

Table 3.1-1. Phase III Work Breakdown Structure

- Task 1 - Design, Fabricate, and Integrate Components
 - Subtask 1.1 - Component Design
 - Subtask 1.2 - Component Fabrication
 - Subtask 1.3 - Component Integration
- Task 2 - Perform Preliminary System Tests
- Task 3 - Perform Proof-of-Concept System Tests
- Task 4 - Evaluate Economics/Prepare Commercialization Plan
 - Subtask 4.1 - Economic Evaluation
 - Subtask 4.2 - Commercialization Plan
- Task 5 - Conduct Site Demonstration
 - Subtask 5.1 - Demonstration Plan
 - Subtask 5.2 - Site Demonstration
- Task 6 - Decommission Test Facility
- Task 7 - Program Management and Reporting
- Task 8 - TSCA Ash Testing
 - Subtask 8.1 - Laboratory Analysis & Surrogate Definition
 - Subtask 8.2 - Pilot-Scale Testing

3.2 Background Patents and Proprietary Data

The basic elements of the proposed coal-fired Vortec Process heater are embodied in U. S. Patent 4,544,394 dated Oct. 1, 1985 and U.S. Patent 4,553,997 dated Nov. 19, 1985. Patent No. 4,957,527, dated September 18, 1990 was filed in accordance with OMB Circ. A-127 Trans. Memo No. 1, patent rights small business firms or non-profit organizations (April 1984). Vortec Corporation has elected to retain title licensing and royalty rights to this patent as per provisions under Contract No. DE-AC22-87PC79651, dated March 11, 1987. Vortec Corporation is in the process of filing additional patents for its process heaters, and will use proprietary information in the execution of this program. Procedures for protecting this proprietary information have been implemented with our subcontractors and consultants via non-disclosure/patent agreements.

4.0 PROJECT STATUS

A two-day test was performed during January to determine the cause of pulsations in the batch feed system observed during pilot-scale testing of surrogate TSCA incinerator ash performed in December of 1993. Two different batch feedstocks were used during this test: flyash and cullet. The cause of the pulsations was traced to a worn part in the feeder located at the bottom of the batch feed tank. The problem was corrected by replacing the worn part with the corresponding part on the existing coal feed tank. A new feeder for the existing coal tank, which had previously been ordered as part of the new coal handling system, was procured and installed.

The data from the pilot-scale tests performed on surrogate TSCA incinerator ash during December of 1993 was collected and analyzed. All samples which required chemical analysis were sent to the appropriate independent laboratory, and the resulting analyses were collected. All of the glass produced during the test passed both the Toxicity Characteristics Leach Procedure (TCLP) and the Product Consistency Test (PCT) by approximately two orders of magnitude. The data was also analyzed to determine the partitioning of the surrogate heavy metals and simulated radionuclides among the effluent streams. A draft test report was written based on the data and analyses performed to date. The test report will be released in final form after some additional analyses are performed.

4.1 Design, Fabrication, Component Integration

Equipment maintenance and modifications to improve equipment performance are ongoing. The experimental test facility activities for the last quarter are as follows:

Precombustors

The two precombustors were removed from the system to demonstrate an improved heat rate. The heat loss through the walls of the precombustors resulted in a decrease in temperature of the preheated air from 1200°F to 600°F prior to entering the inlet arms of the CRV. The precombustors were replaced by insulated duct, which will result in nominally 1100°F preheated air feed to the CRV. The improved heat rate will be demonstrated during several tests planned for the second quarter of 1994.

The flame safety system was also reworked as a result of eliminating the precombustors from the test system. The flame safety system is now configured for only one combustion

zone—the counter-rotating vortices in the CRV combustor. This reworked will improve reliability and maintainability by simplifying the overall control system

Combustion and Melting Subsystem

A spool piece section was added to the CRV combustor to increase the combustion residence time. This modification will improve the carbon burn-out in the CRV and should allow the use of larger sized feedstocks. The modified CRV is shown in Figure 4.1-1. This modification required removing the CRV from the test tower and lowering it to the ground level. The CRV was disassembled and all of the refractory was removed. The new spool section was installed between the existing top and bottom sections. The modified CRV was relined using a low cement castable refractory which was cast in place. The modified CRV was then reinstalled in the test tower. The cyclone melter was also relined with a bonded refractory concurrent with the CRV relining. The cyclone melter was relined with existing spare refractory shapes.

Coal Handling Subsystem

The materials required for the installation of the new coal handling system were procured, and installation efforts have begun. The new coal storage and handling system is being installed outside, adjacent to the test facility. The foundation and support steel for the new coal tank was installed. The new tank was delivered and installed. The feeder assembly has been delivered but its installation has not yet been completed.

Controls Subsystem

The controls subsystem consists of a 486 type personal computer, Metra Byte and Digitronics I/O cards, Genesis software, and the additional instrumentation required to integrate the various vendor subsystems into an integrated controls package.

Modifications to the control system to incorporate the controls required for the coal handling system are on going. Modifications to the data recording system were performed to reflect the elimination of the precombustors from the system.

Equipment Design

Vortec continually gets requests asking for the cost of a commercial CMS system. Engineering on conceptual designs is ongoing, and budget pricing for various sizes of equipment are continually being obtained. Our data base on equipment costs is rapidly

Figure 4.1-1 Modified CRV

growing, as well as our conceptual designs for systems with capacities of up to 400 tons per day. Engineering has developed a proprietary computer code for use in developing heat and mass balances as well as for sizing the CRV and cyclone melter for CMS systems. The use of the computer code allows us to rapidly establish the specifications needed to obtain the budget pricing for the various pieces of equipment required in a system.

4.2 Test Operations

4.2.1 Batch Feed Pulsation Diagnostic Testing

A two-day test was performed during January to determine the cause of pulsations in the batch feed system observed during pilot-scale testing of surrogate TSCA incinerator ash performed in December of 1993. Two different batch feedstocks were used during this test: flyash and cullet. A variety of possible sources of the batch feed pulsations were explored. The cause of the pulsations was traced to a worn part in the feeder located at the bottom of the batch feed tank. The initial clearance between the rotor and the housing was 7 mm. Upon inspection, it was noted that the rotor had worn such that the housing clearance had increased to 21 mm. The problem was corrected by replacing the worn part with the corresponding part on the existing coal feed tank. No pulsations were observed during the next pilot-scale test. A new feeder (including end plates, housing and rotor) for the existing coal tank, which had previously been ordered, was procured and installed.

4.2.2 TSCA Ash Testing

The data from the pilot-scale tests performed on surrogate TSCA incinerator ash during December of 1993 was collected and analyzed. All samples which required chemical analysis were sent to the appropriate independent laboratory, and the resulting analyses were collected. All of the glass produced during the test passed both the Toxicity Characteristics Leach Procedure (TCLP) and the Product Consistency Test (PCT) by approximately two orders of magnitude. The data was also analyzed to determine the partitioning of the surrogate heavy metals and simulated radionuclides among the effluent streams. A draft test report was written based on the data and analyses performed to date. The test report will be released in final form after some additional analyses are performed. The following information is a general overview of the information presented in the draft test report.

An additional task was added by the PETC/Phase III program for the pilot-scale melt testing of simulated Toxic Substance Control Act (TSCA) ash. The objective of this testing was to demonstrate the ability of the Vortec Combustion and Melting System (CMS) to remediate ash from DOE operated TSCA waste incinerators processing solid materials with low-level radioactive constituents. The pilot-scale testing was composed of two demonstration tests. The first demonstration test provided a database on the performance and operation of the CMS when vitrifying surrogate TSCA incinerator ash feedstocks. The feedstock (including surrogates for radionuclides) was a mixture of municipal solid waste incinerator (MSWI) bottom ash and fly ash, and heavy metal oxides. The need for additional glass forming agents was determined by laboratory-scale testing. The primary purpose of the first test in the sequence was to evaluate the melting performance and to define the expected range of flue gas emissions from the Vortec CMS when processing a surrogate TSCA incinerator ash containing approximately 5 wt% carbon.

A second demonstration test was performed with a surrogate TSCA incinerator ash containing 12 wt% carbon. The goal of the second test was to obtain additional data on the performance of the CMS when processing simulated TSCA ash and to evaluate the effect of the relatively high carbon content in the ash on the capture rate of the heavy metal and radionuclide surrogates in the vitrified product.

The surrogate TSCA ash was a mixture of municipal solid waste incinerator (MSWI) bottom ash and fly ash, coal, and metal contaminants as shown in Table 4.2-1. The metal contaminants are comprised of the surrogate heavy metals and radionuclides. A combined bottom ash and flyash mixture was used as the base material for the surrogate TSCA ash. Arsenic, barium, cadmium, chromium, and lead were added to the surrogate ash mixture as metal oxides to increase the concentration of these heavy metals to the level desired by DOE. Cerium and cesium were added to the surrogate ash mixture as simulated radionuclides. Simulated radionuclides are non-radioactive metals, the behavior of which will simulate the behavior of the true radionuclide species in the CMS. Cerium was added as cerium oxide to simulate the behavior of uranium within the CMS, for its chemical properties are similar to those of uranium. Cesium was added as cesium chloride, as specified by DOE, to simulate the behavior of radioactive cesium within the CMS. Mercury, selenium, and silver were excluded due to their high cost or because Vortec presently considers these materials to be too hazardous to handle at our pilot facility. However, the metals which were added to the surrogate ash represent both semi-volatile

Table 4.2-1 TSCA Feedstock Formulations and the Resulting Metals Concentration

	Test 1	Test 2		Test 1	Test 2
	lbs	lbs		Concentration of Element	Concentration of Element
			Element	ppm	ppm
MSWI bottom ash	2729	2337			
Fly ash	2145	1837			
Coal	193	600			
As ₂ O ₃	19.8	19.4	As	2975	3082
BaO	12.7	11.5	Ba	3022	2877
CdO	16.65	16.35	Cd	2910	3019
Cr ₂ O ₃	18.6	18.6	Cr	2938	3026
PbO	1.1	2.4	Pb	2730	2757
CeO ₂	15.0	14.7	Ce	2361	2453
CsCl	15.4	14.7	Cs	2353	2382

and non-volatile metals; therefore, the behavior of the excluded metals can be estimated based on the behavior of the metals included in the surrogate ash.

The carbon content of the surrogate TSCA ash varied between the two tests to study its effect on the capture rate of the heavy metal and radionuclide surrogates in the vitrified product. The carbon content of the surrogate ashes used in the feasibility tests were 5 wt% and 12 wt%. In order to vary the carbon content of the ash mixture, appropriate quantities of pulverized coal were added to the surrogate ash mixture. The chemical composition of the coal used as an additive in the feasibility testing is listed in Table 4.2-2.

The batch tank was loaded with the appropriate surrogate ash and coal feedstock, and the feedstock was pneumatically blended. The resulting chemical composition of the blended feedstocks is presented in Table 4.2-3.

Prior to the initiation of either of the feasibility tests, the system was brought to a temperature of approximately 2500°F. The first test was conducted using the 5% carbon feedstock. The test (Test 1a) was initially conducted using a molten glass temperature of 2500°F at a feed rate of 1000 lbs/hr. Later the test conditions were changed (Test 1b) by allowing the glass temperature to decrease to 2300°F to investigate the effect of temperature on the partitioning of the metal contaminants among the effluent streams.

The second test was conducted using the feedstock containing 12% carbon. During the initial portion of this test (Test 2a) the molten glass temperature was held at 2300°F and the

Table 4.2-2 Chemical Composition of Coal

Proximate Analysis	dry wt%	Ash Analysis	dry wt%
ash	1.23	SiO ₂	47.17
volatile	35.38	Al ₂ O ₃	30.9
fixed carbon	63.39	K ₂ O	1.46
sulfur	0.61	Na ₂ O	1.32
		CaO	3.46
Ultimate Analysis	wt %	Fe ₂ O ₃	10.09
carbon	85.44	MgO	0.89
hydrogen	5.32	SO ₃	1.32
nitrogen	1.62	BaO	0.32
chlorine	-	TiO ₂	1.89
sulfur	0.61	P ₂ O ₅	0.31
ash	1.23	SrO	0.39
oxygen	5.78	Mn ₃ O ₄	0.06

Table 4.2-3 Chemical Composition of the Combined Feedstocks

Element	Oxide	Test 1 wt% of oxide	Test 2 wt% of oxide
Al	Al ₂ O ₃	9.1466	8.6063
As	As ₂ O ₃	0.3927	0.4068
Ba	BaO	0.3384	0.3222
B	B ₂ O ₃	0.1226	0.1028
Cd	CdO	0.3317	0.3442
Ca	CaO	17.738	17.227
Ce	CeO ₂	0.2904	0.3017
Cs	CsCl	0.2981	0.3017
Cl	Cl	3.6794	3.3415
Cr	Cr ₂ O ₃	0.4289	0.4417
Fe	Fe ₂ O ₃	6.052	5.3874
Pb	PbO	0.2949	0.2977
Mg	MgO	4.9534	5.502
K	K ₂ O	1.463	1.3131
Si	SiO ₂	33.0417	30.4023
Na	Na ₂ O	3.463	3.1379
S	SO ₃	3.406	3.358
C	C	5.013	12.184
Hg	HgO	ND	ND
Se	Se	2 ppm	5 ppm
LOI		13.11	20.80

ND ≡ Not detected.

feed rate was set at 500 lbs/hr. Later during the test (Test 2b), the feed rate was increased to 1000 lbs/hr and the temperature was increased to 2450°F.

Glass samples were taken continuously during both feasibility tests in two forms: glass patty, which was air quenched, and glass cullet, which was water quenched. The glass samples were obtained, handled, and prepared for analysis according to the sampling and custody procedures described in the test plan. The glass chemistry and PCT analyses were conducted by Corning Engineering Laboratory Services (CELS), and the TCLP testing was conducted by Blue Marsh Laboratories. Also, the feed rate and temperature were held constant so that EPA Method 5 sampling of the flue gas effluent could be conducted.

From a qualitative standpoint, the glass produced from the surrogate TSCA ash was consistently black in color throughout both tests. Within a single glass sample, no color variations could be seen in the glass cullet. Table 4.2-4 presents the chemical composition of the glass formed during the feasibility tests. The chemical analysis was performed by CELS.

The effect of operating temperature and carbon content in the ash on the composition of the glass seems to be negligible for all the glass forming compounds and the metal contaminants, except for cadmium. The concentration of cadmium in the glass increased by a factor of two for Test 2a—the low temperature, low feed rate test.

Both glass cullet and glass patty samples, collected during both feasibility tests, were sent to Blue Marsh Laboratories for TCLP testing. The TCLP leachates were analyzed for the metal contaminants added to the surrogate TSCA ash. The results of the TCLP testing, along the concentration of the metal contaminants in the glasses, are displayed in Table 4.2-5. All the TCLP analyses indicate that all the glass produced during Vortec's feasibility testing has excellent leach resistance for the heavy metals and simulated radionuclides.

Both glass cullet and glass patty samples, collected during both feasibility tests, were also sent to CELS for PCT analysis. CELS performed PCT procedure B on the glasses, and analyzed the leachates for the glass forming elements (K, Na, B, Ca, Mg, and Si). The PCT testing followed all the specifications of PCT procedure A, but PFA Teflon vessels were used instead of stainless steel. CELS also reported the final pH of the leachate. The results of the PCT testing are displayed in Table 4.2-6. The current PCT specification for nuclear waste glasses is a weight loss of 1 g/m²/day for Li, Na, K, Si, and B combined. The PCT result for the vitrified product result in a Na-normalized glass leach rate of approximately 0.02 g/m²/day.

Table 4.2-4 Chemical Composition of Glass Produced during Feasibility Tests

Compound	Test 1a	Test 1a	Test 1b	Test 1b	Test 2a	Test 2a	Test 2b	Test 2b
	Glass Cullet	Glass Patty	Glass Cullet	Glass Patty	Glass Cullet	Glass Patty	Glass Cullet	Glass Patty
	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%
Cs ₂ O	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
K ₂ O	0.73	0.76	0.76	0.74	0.78	0.78	0.68	0.68
Na ₂ O	2.88	2.86	2.91	2.91	2.91	2.91	2.74	2.75
Al ₂ O ₃	12.5	12.2	12.4	12.6	11.8	11.9	11.9	12.0
As ₂ O ₃	0.14	0.12	0.15	0.14	0.17	0.15	0.16	0.13
B ₂ O ₃	0.17	0.16	0.18	0.19	0.14	0.14	0.14	0.15
BaO	0.38	0.39	0.38	0.38	0.36	0.38	0.40	0.39
CaO	22.5	22.3	22.1	22.1	21.6	21.9	22.4	22.6
CdO	0.023	0.02	0.042	0.039	0.080	0.081	0.033	0.035
CeO ₂	0.24	0.32	0.28	0.29	0.46	0.27	0.35	0.28
Cr ₂ O ₃	0.48	0.47	0.47	0.47	0.44	0.45	0.52	0.51
Fe ₂ O ₃	7.60	7.75	7.48	7.37	7.51	7.61	7.46	7.53
HgO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MgO	6.29	6.10	6.52	6.53	7.10	7.20	7.23	7.37
PbC	0.16	0.16	0.17	0.17	0.17	0.19	0.15	0.15
SiO ₂	42.2	42.9	42.3	42.3	42.7	43.1	42.0	42.2
C	0.008	0.008	0.007	0.007	0.008	0.009	0.008	0.009
SO ₃	0.17	0.17	0.068	0.049	0.044	0.045	0.031	0.038
Se	<1 ppm	<1 ppm	<1 ppm	<1 ppm	<1 ppm	<1 ppm	<1 ppm	<1 ppm
Cl	0.29	0.32	0.27	0.20	0.069	0.088	0.12	0.13

Table 4.2-5 Glass TCLP Results with Corresponding Metals Concentrations

	Glass Cullet Glass Composition ppm	Glass Cullet TCLP ppm	Glass Patty Glass Composition ppm	Glass Patty TCLP ppm	TCLP RCRA Limit// Practical Quantitation Limit ppm
Test 1a					
As	1061	ND	909	ND	5.0 // 0.1
Ba	3393	0.14	3482	0.14	100. // 0.05
Cd	202	ND	175	ND	1.0 // 0.02
Cr	3288	ND	3219	ND	5.0 // 0.02
Pb	1482	0.3	1482	0.3	5.0 // 0.1
Ce	1951	0.1	2602	0.1	NA // 0.1
Cs	187	ND	283	ND	NA // 0.1
Test 1b					
As	1136	0.4	1061	ND	5.0 // 0.1
Ba	3393	0.14	3393	0.19	100. // 0.05
Cd	368	ND	342	ND	1.0 // 0.02
Cr	3219	ND	3219	ND	5.0 // 0.02
Pb	1574	0.2	1574	0.2	5.0 // 0.1
Ce	2276	0.1	2358	0.2	NA // 0.1
Cs	187	ND	187	ND	NA // 0.1
Test 2a					
As	1288	ND	1136	ND	5.0 // 0.1
Ba	3214	0.16	3393	0.20	100. // 0.05
Cd	702	0.02	711	0.03	1.0 // 0.02
Cr	3014	ND	3082	ND	5.0 // 0.02
Pb	1574	ND	1759	0.1	5.0 // 0.1
Ce	3740	0.1	2195	0.2	NA // 0.1
Cs	187	ND	187	ND	NA // 0.1
Test 2b					
As	1212	ND	985	ND	5.0 // 0.1
Ba	3571	0.09	3482	0.19	100. // 0.05
Cd	290	ND	307	ND	1.0 // 0.02
Cr	3562	ND	3493	ND	5.0 // 0.02
Pb	1389	ND	1389	0.1	5.0 // 0.1
Ce	2846	0.1	2276	0.2	NA // 0.1
Cs	187	ND	187	ND	NA // 0.1

ND ≡ The compound indicated was not detected at or above the practical quantitation limit.
NA ≡ Not applicable.

Table 4.2-6 PCT Results of the Glasses Produced during Feasibility Testing

	Test 1a Glass Cullet ppm	Test 1a Glass Patty ppm	Test 1b Glass Cullet ppm	Test 1b Glass Patty ppm	Test 2a Glass Cullet ppm	Test 2a Glass Patty ppm	Test 2b Glass Cullet ppm	Test 2b Glass Patty ppm
K	1.8 1.8	2.0 2.1	2.6 2.5	2.4 2.4	2.5 2.4	4.3 4.1	2.5 2.6	2.9 2.8
Na	5.3 5.3	5.6 5.8	7.0 6.8	6.5 6.4	8.5 8.4	12.1 11.8	7.3 7.5	8.0 8.0
B	0.13 0.12	0.12 0.12	0.14 0.13	0.14 0.13	0.15 0.15	0.20 0.19	0.14 0.14	0.17 0.16
Ca	17.3 17.7	17.1 17.6	20.6 20.1	20.4 20.7	22.3 22.3	16.4 16.2	22.7 23.2	23.8 23.9
Mg	0.007 0.005	0.006 0.005	0.004 0.004	0.004 0.003	0.004 0.003	0.010 0.007	0.004 0.003	0.004 0.002
Si	14.5 14.3	15.1 15.0	16.3 16.2	16.4 16.6	16.3 16.6	16.3 16.3	17.1 16.8	16.8 16.9
pH	10.7 10.7	10.8 10.8	10.9 11.0	11.0 11.0	11.1 11.1	11.0 11.0	11.0 11.0	11.1 11.1

NOTE: The initial pH of the extraction solution was 4.9.

4.3 Commercialization Planning

The Business Plan has been completed. Vortec is actively marketing the process for glass melting, industrial waste treatment, and contaminated site remediation applications.

4.4 Project Management

A meeting was held in February with the PETC Program Manager at PETC to review program status.

The Semi-Annual Summary Report of DOE-Owned Plant and Capital Equipment was submitted to DOE as per contract requirements.

5.0 PLANNED ACTIVITIES

The data from the surrogate TSCA pilot-scale melt trials has been reduced and analyzed, and the results of this analysis was incorporated into a draft comprehensive Test Report. The Draft test report has been issued to DOE for comments. Any comments received from DOE will be incorporated and a final Test Report will be issued

Final modifications to the test system will be completed shortly. After the modifications are complete, the demonstration testing will begin.

A Test Plan has been completed for the Demonstration testing and is currently undergoing internal review. The Test Plan will be submitted to DOE early next quarter for review. The Demonstration Test is currently planned for the end of June.

6.0 SUMMARY

The TSCA ash testing was completed and the data indicates the Vortec CMS can successfully process surrogate TSCA ash, resulting in a fully-reacted, leach resistant, vitrified product without the need for additional glass forming agents. This will allow the safe disposal of the ash. Optimization testing using the TSCA ash should be performed to determine the optimal ranges of operating temperatures and feed rates. The operating temperatures used in the feasibility testing were higher than required for effective operation of the CMS. Experience has shown that molten flyash has a steep viscosity curve. Due to lack of experience with the surrogate TSCA ash, higher system temperatures (approximately 100-200°F higher than required) were used throughout the feasibility testing to ensure proper operation, without concern of plugging. Additional testing using the simulated TSCA ash will be performed as funding permits.

All of the facility modifications will be completed shortly and demonstration testing will begin. The demonstration testing will be conducted using utility boiler flyash as the primary feedstock component.

It is anticipated that the program will be completed on schedule and within the original budget.

DATE

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9/14/94

END