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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

JULY 1993 - SEPTEMBER 1993

PREPARED FOR

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

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TABLE OF CONTENTS

SECTION	TITLE	PAGE
1.0	EXECUTIVE SUMMARY.....	3
2.0	INTRODUCTION/BACKGROUND	4
2.1	Introduction.....	4
2.2	Background.....	4
2.3	Objectives	9
3.0	PROJECT DESCRIPTION	11
3.1	Program Description.....	11
3.2	Background Patents and Proprietary Data.....	12
4.0	PROJECT STATUS.....	14
4.1	Design, Fabrication, Component Integration	14
4.2	Test Operations.....	20
4.3	Commercialization Planning	31
4.4	Project Management	31
5.0	PLANNED ACTIVITIES	31
6.0	SUMMARY	32

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LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.2-1	Artist Rendering of Basic CMS	6
2.2-2	Vortec Ash Vitrification and Recycling System	8
3.1-1	Phase III Program Schedule	11
4.1-1	CRV Lid Modifications Design Option 1	16
4.1-2	CRV Lid Modifications Design Option 2	17
4.2-1	Schematic of Method 5 Sampling Train	26

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1-1	Phase III Work Breakdown Structure	11
4.2-1	SPL Chemical Composition	21
4.2-2	Test 69 Product Glass TCLP Results	24
4.2-3	Test Matrix and Schedule	28
4.2-4	Characterization of TSCA Ash & Surrogate Ash	29
4.2-5	Chemical Composition of Combined Bottom Ash and Fly Ash	29
4.2-6	Chemical Composition of Coal	30

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 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.

During the past quarter, the major effort was completing some of the system modification installation designs, completing industry funded testing, developing a surrogate TSCA ash composition, and completing the TSCA ash Test Plan. The installation designs will be used for the equipment modifications planned for the end of CY 93.

The industry funded testing consisted of vitrifying Spent Aluminum Potliner (SPL) which is a listed hazardous waste. This testing has verified that SPL can be vitrified into a safe, recyclable glass product. Some results from this testing are provided in Section 2.2.1

The surrogate TSCA ash composition was developed with input from various DOE laboratories and subcontractors. The surrogate ash consists of a mixture of MSW fly ash and bottom ash spiked with heavy metal contaminants. The levels of metal additives are sufficient to ascertain the partitioning of the contaminants between the glass and effluent flow streams. Details of the surrogate composition and the planned testing is provided in Section 4.2.2.

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 multi-fuel 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.

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.

3.1 Program Description

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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

During the past quarter, the major effort was completing some of the system modification installation designs, completing industry funded testing, developing a surrogate TSCA ash composition, and completing the TSCA ash Test Plan. The installation designs will be used for the equipment modifications planned for the end of CY 93.

The industry funded testing consisted of vitrifying Spent Aluminum Potliner (SPL) which is a listed hazardous waste. This testing has verified that SPL can be vitrified into a safe, recyclable glass product. Some results from this testing are provided in Section 2.2.1

The surrogate TSCA ash composition was developed with input from various DOE laboratories and subcontractors. The surrogate ash consists of a mixture of MSW fly ash and bottom ash spiked with heavy metal contaminants. The levels of metal additives are sufficient to ascertain the partitioning of the contaminants between the glass and effluent flow streams. Details of the surrogate composition and the planned testing is provided in Section 4.2.2

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:

Air Preheat Subsystem

The air preheat subsystem consists of the combustion air blower, indirectly fired air preheater, the low temperature piping from the blower to the pilot burners and air preheater, and the high temperature piping from the air preheater to the coal combustors. In Phase III the air preheater will be replaced with a shell type recuperator for waste heat recovery. Due to current funding considerations, engineering for this modification has been minimal and construction for this modification has not begun.

Combustion and Melting Subsystem

This subsystem consists of the CRV combustor, cyclone melter, gas pilot burner, gas and coal injectors, and combustion controls.

After the last test run in June, an inspection of the unit indicated that it was time to replace the refractory. A section of refractory about one square foot in area adjacent to the upper inlet arm of the CRV was worn through. Hot glass had washed away the insulating castable behind the hot face refractory forming a channel which then exited several feet lower in the CRV. The damage was too extensive to repair, so the refractory was replaced with AZS refractory spares that were on hand. The cyclone melter refractory showed signs of wear, but it was not as severe as in the CRV. However, since both the CRV and cyclone melter had to be removed from the test loop in order to repair the CRV, it was decided to replace the cyclone melter refractory at the same time.

It was very difficult to access the extent of the damage to the refractory through the view port and the injector opening in the top of the CRV lid. Even dropping a video camera into the CRV did not present a complete picture of the damage. This would present a drawback to the CMS in commercial usage. As a result, several schemes for a removable lid for the CRV were designed. Sketches of the designs are shown in Figures 4.1-1 and 4.1-2. These sketches are only concepts at this point as a design review has not been performed as yet.

Flue Gas Quench/Cleanup Subsystem

This subsystem consists of a spray quench channel, wet electrostatic precipitator (WESP), ID fan, stack assembly, and the cullet quench assembly.

The WESP was added to the test loop in the second quarter of the current fiscal year. As warmer weather was coming up and the test loop was needed for testing operations, it was decided to delay the installation of the freeze protection to the water piping circuits for the WESP. Heat tracing, insulation and aluminum lagging was purchased in September and installation of the freeze protection was initiated. The installation should be completed by mid-October.

Flue gases leaving the WESP are at saturated conditions. In cool weather the flue gases continue to lose heat as they pass through the ID fan and out the stack. As a consequence, water condenses out and is discharged from drains in the ID fan and the stack. In order to maintain our philosophy of a zero waste discharge system, a sump was added adjacent to the ID fan to collect the water discharged from the drains. A sump pump with automatic level control was added to send the collected water back to the WESP. Piping and the sump was heat traced and insulated for freeze protection.

(16)

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Figure 4.1-1 CRV Lid Modifications Design Option 1

(17)

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Figure 4.1-2 CRV Lid Modifications Design Option 2

The WESP normally operates with a field voltage of about 35 Kilovolts. As the collector plates get dirty this voltage starts to fall off, indicating that a wash down of the collectors is required. We have had problems with the requirement for frequent wash downs, often every two hours. The manufacturer was contacted and they provided assistance in establishing various water pressure settings to help eliminate the problem, but the problem persisted. Finally, we checked the fog nozzles and that all but two of the forty nozzles were clogged with particulate.

The fog nozzles are located below the collector plates. Their purpose is to produce a fine mist that will coat the particulate as it enters the collecting area. The WESP then depends upon the resistivity of water for the collection efficiency rather than the resistivity of the particulate, which can vary widely. As the water droplets with the entrained particulate are collected, the droplets coalesce and roll down the collector plates. The continual washing of the plates with the water is a self cleaning action. Since the WESP was collecting the particulate efficiently, it was previously assumed that the fog nozzles were operating properly. Since the nozzles have been cleaned, we have not experienced the problems which we were having before, however, we have not operated that often since the nozzles were cleaned.

Water collected in the base of the WESP must be sent back to the recirculation tanks in the pump house for recycling back to the WESP. The return pumps are controlled by float type limit switches installed in the side of the WESP. When the water level gets too high in the WESP the pumps come on and when the water level gets low the pumps shut off. Particulate removed by the WESP has been getting into the pivot point for the float thereby rendering it inoperable. This has caused numerous WESP alarms due to high water level. A new limit switch assembly has been purchased¹ and installed to eliminate this problem. The new assembly is like a sight gauge with a magnetic float inside the sight tube. Magnetic reed switches are strapped to the sight gauge at the level where the alarm and control points are to occur. The clearance between the float and sight tube is limited and particulate buildup on the sight tube could cause problems. However, the unit was installed such that the sight tube can be cleaned easily should a buildup occur.

Coal Handling Subsystem

The existing coal handling system limits the test loop to about ten hours of operation on coal. Under Phase III a new coal handling subsystem will be installed which will allow

unlimited operation under coal. The existing coal handling subsystem will be converted to batch handling operations to further support unlimited operation of the test loop.

The coal handling subsystem has been purchased and vendor drawings submitted over the summer months has allowed us to complete the layout drawings and structural steel support drawings necessary for the subsystem installation. Components for the subsystem are being delivered, but not enough has been received yet to begin equipment installation. However, structural steel for support of the new coal tank has been delivered and installed upon existing foundations. A specification for the weatherproof enclosure around the drum dump station has been completed and preliminary cost estimates have been received.

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.

We had been having some problems with the WESP alarm circuits integrating with the Genesis software in the personal computer used to control the overall process. A small programmable controller was purchased and installed in the WESP control loop to separate the WESP from Genesis. This has worked out well and the false alarms from the WESP controls have disappeared.

Although the Genesis software is very powerful, we have had problems in the past with PC reliability. We have been adding loop controllers and small programmable controllers to the test loop in order to eliminate loss of control problems encountered when the PC "locks up". Now the test loop can be controlled manually without the PC, or as an integrated system with the PC interfacing between the various subsystem controls to yield fully automatic operation.

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 growing, as well as our conceptual designs for systems with capacities of up to 400 tons per year. 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 need to obtain the budget pricing for the various pieces of equipment required in a system.

4.2 Test Operations

4.2.1 Spent Potliner Testing

During the last quarter, a test was conducted using Spent Aluminum Potliners (SPL) as the feedstock. This test was independently funded by the generator of the potliner. The purpose of the test was to evaluate the feasibility of processing SPL in the Vortec CMS to produce a safe, recyclable glass product. The SPL feedstock consists of a anthracite coal liner and refractory insulation materials and is a listed hazardous waste (K088) because it contains measurable quantities of cyanide which can leach from the SPL if it is exposed to rain. During the first test, the CMS produced a fully oxidized, non-leachable glass. Based on these results, the SPL generator elected to fund three additional tests to collect data for a petition to delist the glass product.

The SPL was crushed and screened to minus 40 mesh using Vortec's vibrating ball mill. This material was weighed and 250 kg was set aside for each test. The chemical composition of the SPL used for this test is provided in Table 4.2-1.

The SPL and additional glass forming materials consisting of silica sand, limestone, and glass cullet were loaded into the batch tank and air-blended. Carryover from the air-blending was collected in a bag house and returned to the batch tank prior to the start of the test.

For this test, oxygen was also introduced co-axially with the feedstock into the top of the CRV. The oxygen allows for more rapid combustion of the large amount of carbon in the SPL prior to the melting of the inorganic constituents. A commercial SPL process unit could be designed to provide additional residence time in the CRV combustor to allow complete combustion of the carbon without the use of oxygen.

The feedstock was introduced along the longitudinal centerline of the CRV. The feedstock was rapidly heated in the flame zone and the carbonaceous materials are rapidly volatilized and incinerated and the metal contaminants are oxidized.

Table 4.2-1 SPL Chemical Composition

Determination	Pulverized SPL (Wt. %)
Na ₂ O	23.8
Al ₂ O ₃	22.8
CaO	2.57
Fe ₂ O ₃	2.02
SiO ₂	16.5
SO ₃	0.27
C	23.8
F	13.2

Prior to the tests, the system had been idling with refractory temperatures maintained at approximately 2700°F. Before the batch feed began, oxygen flow was initiated at approximately 250 lbs/hr. This flow rate was selected based on the success of the first treatability test conducted previously. Oxygen flow was maintained throughout the tests to assist in the complete combustion of the carbon.

Test 68

For the first test, Test 68, of this set, the system thermal input to the CRV was ramped down to approximately 1.6 MM BTU/hr, because of the high carbon content of the SPL, and the SPL batch feed was initiated. The SPL was initially fed to the system at a rate of approximately 300 lbs/hr. The feed rate stabilized at about 220 lbs/hr after approximately 15 minutes. The feed rate remained relatively constant throughout the remainder of the test. The feed rate and thermal input remained relatively constant until all of the feedstock was processed. No operational problems were experienced during this test, and at the conclusion of the test the system was idled at 2000°F overnight for Test 69.

Test 69

The second test, Test 69, was performed in a slightly different manner than the first one. The SPL feedstock commenced at a constant feed rate of approximately 220 lbs/hr and a CRV thermal input of 1.7 MMBTU/hr. However, with about 200 lbs of the feedstock remaining in the batch tank, the batch feed was halted, and the oxygen feed was stopped to

note the effects of running the system without oxygen enrichment. The batch feed was restarted at a rate of approximately 200 lbs/hr, and run until the tank was empty.

The test with no oxygen was conducted after all of the data and glass samples were collected for the delisting petition. All of the glass produced during the no-oxygen test was drained into a separate cullet cart and was not intermingled with the glass produced for delisting purposes. The glass remained fully oxidized and no operational problems were experienced when operating without oxygen.

Test 70

On the third day, the final test of the series, Test 70, was performed. The feed rate of the SPL feedstock started and continued throughout the entire test at a rate of approximately 240 lbs/hr. After the batch feed commenced, the thermal input was ramped down as in the previous test to about 1.7 MMBTU/hr. At 12:00 noon, the cullet cart containing the glass produced for the delisting petition was removed and the glass draining from the system was diverted to a new cullet cart. This was done so that the process conditions could be changed without contaminating the delisting petition glass samples. The thermal input was then decreased to 1.3 MMBTU/hr in an effort to bring the system temperatures down. This was done to determine the lowest temperature at which the process could operate and still produce an acceptable product. The system temperatures decreased from nominally 2500°F to 2350° with no apparent change in product. The feedstock was exhausted when the system reached 2350°. From a glass product quality standpoint, it appears that the lower operating temperature is acceptable.

Flue Gas Sampling

During the course of Tests 68 and 70, the system was held at a constant feed rate and thermal input for 1 hour so that an isokinetic flue gas particulate sample could be obtained using EPA Method 5 procedures and data could be recorded for the calculation of an accurate heat and mass balance. For Test 69, a particulate capture was performed and the particulate was sent out for analysis.

Glass Product Testing and Evaluation

Samples of the glass cullet for each of the tests was collected by an independent laboratory for detailed analysis to be included in the delisting petition. Additional samples were collected by Vortec for independent analysis. The glass chemistry and physical property analyses were conducted by Corning Engineering Laboratory Services (CELS) and the

TCLP testing was conducted by Blue Marsh Laboratories. The testing of the particulate captured during Test 69 was conducted by Blue Marsh Laboratories.

Glass Chemistry

From a qualitative standpoint, the glass produced from the SPL was green in color which generally indicates that the glass is fully oxidized. The chemistry analysis shows that the majority of the fluoride in the SPL was volatilized and not incorporated in the glass matrix. On a theoretical basis, if none of the fluoride was volatilized, the glass would contain approximately 10.1% fluoride. Therefore, only about 11.2%, of the total fluoride in the SPL was captured in the glass for the first test, 6.2% with oxygen and 3.1% without oxygen for the second test, and 10.2% for the final test. The lower fluoride capture rate during the second test is the result of a higher system operating temperature during this test. Tests 68 and 70 were conducted with a cyclone melter temperature of approximately 2520°F, and Test 69 was conducted with a melter temperature of approximately 2600°F

The glass chemistry also indicates the effect of system operating temperature on sodium volatilization. During the very first test that used actual SPL, Test 62, only approximately 50% of the total available sodium in the batch was captured in the glass with a system operating temperature of approximately 2750°F. For the current set of tests, the capture rate was improved to approximately 69% for Test 68, 59% for both phases of Test 69, and 69% for Test 70. Because it appears that the glass can be melted as low as 2350°F, the capture rate of both the sodium and the fluoride could potentially be improved further.

The carbon was effectively burned off during all three tests. The surprising result is that the lowest carbon content glass was produced when the system was not operating with oxygen enrichment. The glass oxidation state did not change with the removal of the oxygen and the CMS operated normally. Based on the glass chemistry and the CMS performance, it appears that oxygen will not be necessary to process SPL.

The remaining chemical species remained relatively stable with little volatilization or carryover. Based on the glass product chemistry, the glass produced is very stable and essentially non-leachable.

Glass Product TCLP

Two samples of glass cullet taken from the second test, one from the portion of the test run with oxygen the other without, were sent to Blue Marsh Laboratory for TCLP testing. The

results of this testing is provided in Table 4.2-2. As can be seen in the table, the TCLP extract from both samples contained no detectable quantities of RCRA metals, except for a small concentration of mercury which was well below the TCLP limit. Also, the cyanide and fluoride concentrations for both samples were below 0.5 ppm. During the previous test no fluoride or cyanide was detected and the samples for the delisting petition also did not leach any cyanide or fluoride; therefore, a second glass sample was sent for TCLP testing to determine if there was contamination of the sample or an error in these results. The results from this sample indicated no cyanide or fluoride in the leachate.

Method 5 Flue Gas Sampling Results

The flue gas effluent was sampled using Method 5 procedures for particulates, fluoride, and cyanide by Comprehensive Safety Compliance, Inc. (CSC). The main sampling location for the Method 5 test is after the spray quench system and before the wet ESP. Therefore, emission rates for water soluble species, such as fluoride and cyanide, must also take into account the quantity "washed" in the spray quench channel. For the first test, an additional sampling location was included after the wet ESP.

Table 4.2-2 Test 69 Product Glass TCLP Results

	Test 69 (w/O2)	Test 69 (wo/O2)	Test 69 Repeat Sample	P.Q.L.	TCLP Limit
Arsenic	ND	ND	-	0.1	5.0
Barium	ND	ND	-	0.05	100.
Cadmium	ND	ND	-	0.02	1.0
Chromium	ND	ND	-	0.02	5.0
Lead	ND	ND	-	0.1	5.0
Mercury	0.004	0.007	-	0.002	0.2
Selenium	ND	ND	-	0.05	1.0
Silver	ND	ND	-	0.02	5.0
Fluoride	0.4	0.3	ND	0.1	-
Cyanide	0.374	0.115	ND	0.01	-

Approximately 864 ppm of fluoride was detected on the inlet side of the wet ESP for the first test, and 2.6 ppm after the wet ESP. For Test 70, about 720 ppm of fluoride was measured before the wet ESP. The cyanide levels for both tests were below the analytical limits of 1 ppb. The crushed SPL was also sent out for laboratory analysis of its cyanide content. The SPL contained 499.5 ppm of cyanide.

The particulates were isokinetically sampled using the sampling train configuration presented in Figure 4.2-1. The data indicates a particulate emission rate for the first test of approximately 23.35 lbs/hr before the wet ESP, and 0.24 lbs/hr after. The sampling performed during the third test resulted in a particulate emission rate of about 27.99 lbs/hr before the wet ESP. Detailed analysis of the CSC data indicates that the measured flue gas flow rate before the wet ESP of 550 dscf/min for Test 68, and 580 dscf/min for Test 70, are almost twice the calculated flow rates of 312 dscf/min and 308 dscf/min for Test 68 and 70, respectively. Discussions with CSC indicate that the calculated flow rate could be more accurate than the measured flow rate because of inaccuracies in the measurements and the variability of the flue gas. If the particulate emission rates are recalculated based on the calculated flue gas flow rates, then the new particulate emission rates are 13.25 lb/hr and 14.86 lb/hr for the first and third tests. Approximately 5.75 lb/hr of particulate was also captured for the first test in the spray quench water giving a total particulate emission rate of 19 lb/hr. During the third test, about 3.92 lbs/hr of particulates were entrapped in the spray quench water, resulting in a total uncontrolled carryover rate of approximately 18.78 lbs/hr.

Overall the test was very successful with no operational problems. The feedstock was easily transported and injected into the CMS where it melted readily. The CMS was able to completely oxidize the carbon prior to the formation of the glass. The glass produced appeared to be fully oxidized and contained very little unmelted batch. The glass product also easily passed TCLP regulatory requirements. Because of the success of these test, the SPL generator is funding additional testing to be conducted in November.

4.2.2 TSCA Ash Testing

A Test Plan was developed for the pilot-scale vitrification testing of surrogate TSCA incinerator ash. The testing is composed of two demonstration tests which will provide a database on the performance and operation of the CMS when vitrifying surrogate TSCA incinerator ash feedstocks. The feedstock (including surrogates for radionuclides) will be a

Figure 4.2-1 Schematic of Method 5 Sampling Train

mixture of municipal solid waste incinerator (MSWI) bottom ash and fly ash, and heavy metal oxides. The need for the addition of glass forming agents will be determined by laboratory-scale testing (Subtask 8.1). The primary purpose of the first test in the sequence is 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 2 wt% carbon. Success will be measured by the ability of the CMS to produce a vitrified product which passes both TCLP and PCT. Samples of the effluent streams will be taken to establish the partitioning of the heavy metal and radionuclide surrogates.

A second demonstration test will be performed with a surrogate TSCA incinerator ash containing 12 wt% carbon. The goal of the second test is 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 proposed test matrix for the Phase I program is summarized in Table 4.2-3. The test program will consist of 2 test runs, with run times in the range of 4-6 hrs at a nominal feed rate of 1000 lbs/hr. All tests will be performed with natural gas as the fuel.

The primary objective of the first demonstration test is to obtain experience in surrogate TSCA ash processing and to obtain baseline emissions data when using the surrogate ash as a feedstock. Throughout the test, the glass will exit the separator reservoir at the tap hole closest to the melter exit. Steady state glass flow will be established, and the glass will be allowed to flow for approximately 4 to 6 hours with samples taken every 30 minutes. At some point during steady state flow, an EPA Method 5 procedure will be performed by a qualified analytical laboratory. The data obtained by the Method 5 test, along with the data logged by Vortec's computer-based process controller and test personnel, will be used to perform a heat and mass balance around the CMS. This data will also be used to determine the partitioning of the heavy metal and radionuclide surrogates.

The glass samples taken during the first test will be analyzed chemically to determine the composition of the glass and petrographically to determine if any undissolved feedstock materials remain in the glass.

Table 4.2-3 Test Matrix and Schedule

RUN NO.	TEST DURATION (HRS)	FEEDSTOCKS	FUEL/OXIDIZER	TEST SCHEDULE
1	4-6	Low Carbon Content Surrogate TSCA Ash	NATURAL GAS/AIR	To be determined
2	4-6	High Carbon Content Surrogate TSCA Ash	NATURAL GAS/AIR	To be determined

Having established a baseline performance for the vitrification of surrogate TSCA ash using the CMS combustor, the second demonstration test will be run to evaluate the effectiveness of the CMS to capture the heavy metals in the vitrified product when processing a surrogate ash with a high carbon content (12 wt% in surrogate ash).

The surrogate ash will be a mixture of MSWI bottom ash and fly ash, coal, and metal oxides, as shown in Table 4.2-4. Table 4.2-5 lists the composition of the combined MSWI bottom ash and fly ash which will be used as the base component for the surrogate TSCA ash. The carbon content will be varied between the two tests to study its effect on the capture rate of the heavy metals into the vitrified product. The first test will be performed without the addition of coal; therefore, the carbon content of the surrogate ash will be approximately 1.8 wt%. In the second test, pulverized coal will be added to the ash mixture to increase the carbon content to 12 wt%. The chemical composition of the coal is listed in Table 4.2-6. Appropriate quantities of arsenic, barium, cadmium, chromium, lead, and tungsten (all in their oxide forms) will be added to the surrogate ash to increase the concentration of each metal to the values displayed in Table 4.2-4.

A composition being evaluated by DOE for use as a surrogate for TSCA incinerator ash is also shown in Table 4.2-4 for comparison with the surrogates to be used in the vitrification tests. Several compounds in the surrogate being considered by DOE are not included in the surrogate ash for this test program. The F-listed wastes are not included, since these compounds are not truly expected to be present in the TSCA ash, although they are expected to be in the waste processed in the TSCA incinerator. Several metal compounds were excluded due to their high costs or because Vortec presently considers these materials

Table 4.2-4 Characterization of TSCA Incinerator Ash and Surrogate Ash to be used in Testing

Chemical Constituent	Surrogate Ash	Surrogate Ash	Estimated
	Test 1	Test 2	TSCA Ash
	wt%	wt%	wt%
bottom ash (excluding D-listed metals and carbon)	48.1	43.	40.
fly ash (excluding D-listed metals and carbon)	48.1	43.	40.
carbon	1.8	12.	12.
F001 (trichloroethylene)	-	-	1.
F002 (tetrachloroethene)	-	-	1.
F003 (acetone)	-	-	1.
F005 (methyl ethyl ketone)	-	-	1.
D004 Arsenic	.3	.3	.5
D005 Barium	.3	.3	.5
D006 Cadmium	.3	.3	.5
D007 Chromium	.3	.3	.5
D008 Lead	.3	.3	.5
D009 Mercury	-	-	.5
D010 Selenium	-	-	.5
D011 Silver	-	-	.5
Tungsten (surrogate for uranium)	.1	.1	uranium not specified
oxygen associated with metals	.4	.4	NA

Table 4.2-5 Chemical Composition of Combined Bottom Ash and Fly Ash Mixture

	wt%		wt%
SiO ₂	37.4	CdO	0.006
Al ₂ O ₃	10.0	Cr ₂ O ₃	0.07
K ₂ O	1.60	PbO	0.32
Na ₂ O	3.98	HgO	<0.01
CaO	19.7	SeO ₂	<2ppm
Fe ₂ O ₃	5.30	Ag ₂ O	<0.002
MgO	5.13	C	1.81
SO ₃	3.81	Cl	4.1
BaO	0.10	H ₂ O	1.5
		Volatiles	5.17

Table 4.2-6 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

to be too hazardous to handle at our pilot facility. In similar test programs, surrogate compounds have been used to simulate the behavior of hazardous compounds in the CMS. However, the metals which will be added to the surrogate ash represent both semi-volatile 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.

Tungsten will be added to the surrogate ash in the second test as a simulated radionuclide. Simulated radionuclides are non-radioactive metals, the behavior of which will simulate the behavior of the true radionuclide species in the CMS. Tungsten will simulate the behavior of uranium within the CMS, for its chemical properties are similar to those of uranium - tungsten has a large atomic radius, forms the same oxidation states as uranium, and has a vapor pressure similar to that of uranium. Zirconium has been used to simulate the behavior of thorium; however, the refractories currently present within the pilot scale CMS contain zirconium. In similar test programs, zirconium has been found to leach from the refractories into the vitrified product, making it difficult to perform a material balance and determine the partitioning of the zirconium among the effluent streams. Therefore, zirconium will not be added to the surrogate ash.

Based on the composition of the surrogate ash, no glass forming additives appear to be necessary. However, laboratory melt tests will be performed (as part of Subtask 8.1) to

establish the need for additional glass forming agents required to produce a suitable glass which will consistently pass both TCLP and PCT.

The MSWI bottom ash and fly ash, coal as required for test 2, and metal oxides will be blended at Vortec's UPARC facility at a convenient time prior to the test schedule. The resulting contaminated mixture will be stored in 500 lb supersacks.

A copy of the Test Plan will be provided to DOE for review. Testing is tentatively planned for early November.

4.3 Commercialization Planning

The Business Plan was completed and was submitted to Dawnbreaker, a DOE sponsored small business development consulting firm. The Plan was presented to a panel of venture capitalists as part of a DOE sponsored business development program. The overall response to the Plan was favorable and several copies of the Plan were distributed to attendees.

4.4 Project Management

Copies of the revised Management Plan, Cost Plan, Labor Plan, and Schedule Plan were submitted to the Document Control Center as per contract requirements. The revisions to these plans reflect the program changes resulting from Contract Modification A010 which added the new TSCA Ash Testing task.

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 surrogate ash definition for the TSCA ash testing is under way and laboratory melts using the surrogate composition will be completed shortly. The pilot-scale ash testing will then be conducted as soon as the laboratory melts are completed and the metal contaminants can be procured.

The final system modifications are expected to begin in early next quarter. These modifications will include the installation/modification of the batch and coal handling systems and the installation of a radiation recuperator. The installation of the recuperator will complete the system modifications required to make the test loop a completely integrated coal-fired pilot-scale melt system capable of operating on a continuous basis.

6.0 SUMMARY

The TSCA ash testing will be conducted early next quarter. After the TSCA ash testing and the installation of the remaining equipment, several 24 hour proof-of-concept tests will be conducted to shakedown the integrated system. Following these tests, the demonstration tests will be conducted. The demonstration tests are currently planned to begin in early CY 94.

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

DATE

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END