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

CONTRACT DE-AC22-91PC91161

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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 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 concepts to be developed are based on advanced glass melting and ore smelting furnaces developed and patented by Vortec Corporation. 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 current reporting period, three preliminary coal-fired tests were successfully completed. These tests used industrial boiler flyash, sewer sludge ash, and waste glass cullet as feedstocks. The coal-fired ash vitrification tests are considered near term potential commercial applications of the CMS technology. The waste glass cullet provided necessary data on the effect of coal firing with respect to vitrified product oxidation state.

Engineering and design activities in support of the Phase III proof of concept are continuing, and modifications to the existing test system configuration to allow performance of the proof-of-concept tests are continuing.

The economic evaluation of commercial scale CMS processes is continuing. Preliminary designs for 15, 25, 100 and 400 ton/day systems are in progress. This data will serve as input data to the life cycle cost analysis which will be an integral part of the CMS commercialization plan.

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:

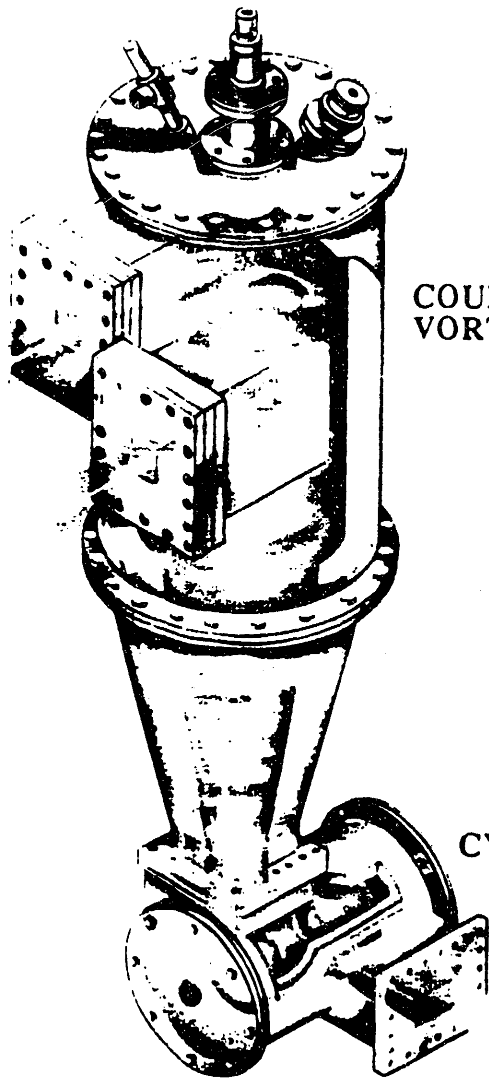
1. Significantly lower capital cost as compared to conventional gas/oil-fired and electric furnaces.
2. Substantially higher thermal efficiency as compared to conventional gas/oil-fired melting furnaces.
3. Satisfaction of projected future emission requirements for NOx, SOx and particulates.
4. The process 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 2-1.

Rapid temperature quenching of the combustion products by the inert waste glass particles and staged combustion are the primary means of limiting NOx emissions. Experimental data obtained during the course of feasibility experiments with the pilot-scale CMS indicate NOx 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 NOx are currently the most stringent in the United States.

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.

Feedstocks/Fuel



COUNTER ROTATING
VORTEX COMBUSTOR

Combustion Air,
Combustion Gases,
or Preheated Feedstocks

CYCLONE MELTER

Combustion Gases &
Vitrified Products

Figure 2-1. Artist Rendering of Basic CMS

A process diagram of a Vortec CMS based commercial ash vitrification and recycling system is shown in Figure 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.

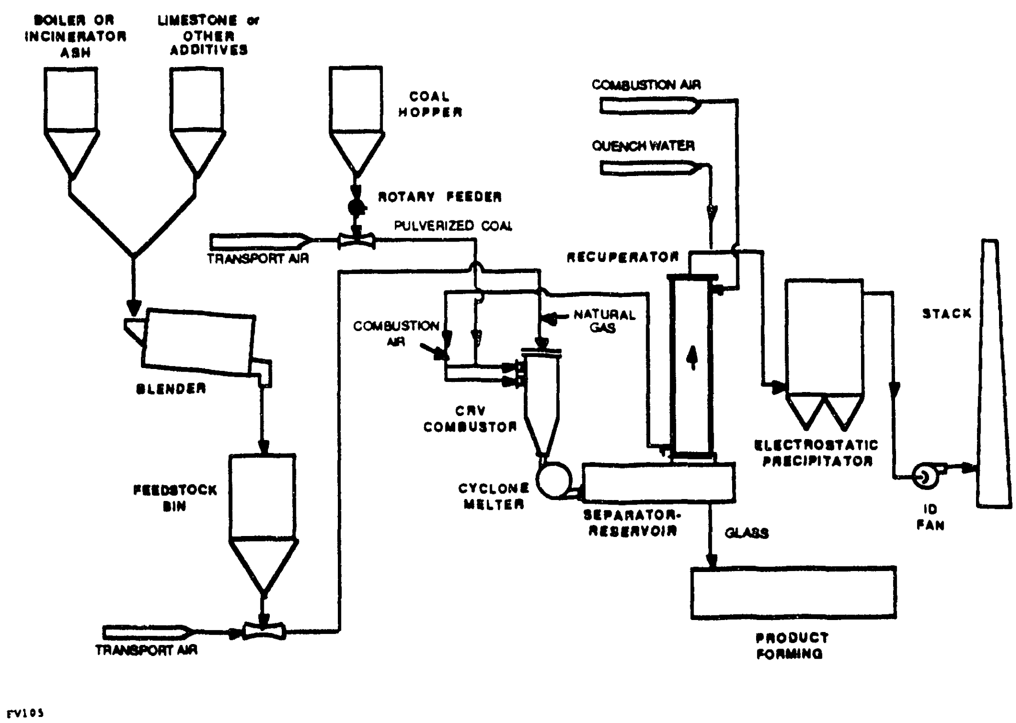


Figure 2-2. Vortec Ash Vitrification And Recycling System

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.

Final 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 CMS indicate that NO_x emissions with coal combustion are lower than the California emission standards 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 SO_2 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 cyclone 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.

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.

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. 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.

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 10^6 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 six (6) technical tasks and a program management task distributed over 36 months as shown in Figure 3-1. The tasks in the contract's Statement of Work are provided below in Table 3-1.

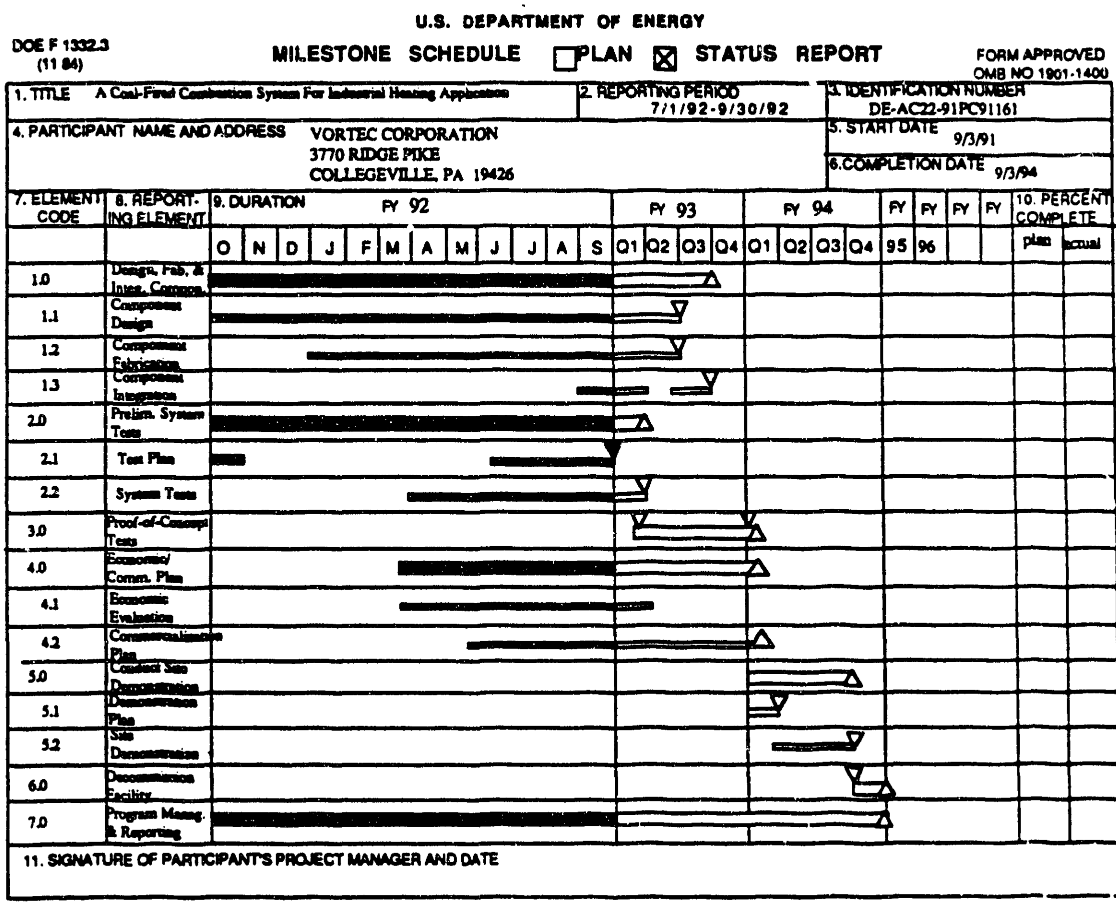


Figure 3-1. Phase III Program Schedule

Table 3-1. 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

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 fourth quarter of the contract performance period), effort has been concentrated on conducting preliminary coal-fired vitrification performance tests with selected ashs and cullet, developing preliminary designs and cost estimates for commercial scale systems, and continuation of commercialization planning. A summary of the activities performed during this reporting period is presented below.

4.1 Design, Fabrication, Component Integration

CMS Refractory Repairs

During the latest testing, the separator/reservoir sustained some refractory damage due to an excessive temperature condition and requires a rebuild. The refractory design and selection for the rebuild has been reviewed by two refractory suppliers (Corhart and Zedmark). Additionally, some minor changes to the separator/reservoir steel have been designed to improve visibility into the system during the tests and accessibility for repairs after the tests.

The following modifications were incorporated into the redesign:

1. The refractory in roof area at the entrance of the separator/reservoir was changed from mullite to AZS to reduce wear experienced in this area,
2. The blast wall area refractory was change to CR-30 to improve wear characteristics,
3. The roof blocks were redesigned to improve crack resistance,
4. The roof of the separator/reservoir was redesigned to improve maintainability with the inclusion of design elements such as removable sections and construction joints,
5. All glass contact refractory was changed to CR-30 to improve corrosion/erosion resistance.

During this modification period, it was decided to also replace the refractory in the cyclone melter. Zedmark has committed to meet our schedule to supply fired CR-30 shapes for the melter replacement refractories.

Air Pollution Control

Integration requirements for the APC assembly were defined and detailed engineering drawings were developed. Figures 4-1 and 4-2 are Plan and Elevation sketches showing the layout and interconnection of the components comprising the flue gas conditioning subsystem. Figure 4-3 is an outline drawing showing the wet ESP in relation to the platform steel. The design for the structural steel and work platform for the new ESP installation was also completed. Equipment foundation designs were developed and site work was started with the demolition of existing equipment and structures in the area where the wet ESP will be installed.

Design work on the evaporative cooler has been completed, as shown in Figure 4-4. The evaporative cooler will cool the flue gas exiting the radiation recuperator from 2100°F to 300°F. The cooler will also be the major support for the recuperator with the recuperator being suspended from the bottom of the cooler. The detailed design drawings have been released to qualified fabricators for bids.

Heat Recovery Subsystem

The radiation recuperator vendor (ECT, Inc.) has supplied the final design drawings for the heat recovery subsystem. Fabrication of the recuperator has been delayed pending approval of 1993 budget allocation.

4.1.2 Component Fabrication

Air Pollution Control System

Fabrication of the WESP was initiated by NAPCO and expected delivery is in late November.

Gas Sampling Flow-Train Modification

The flue gas sampling flow-train was modified and a Perma Pure sampling system was install at the test facility as shown in Figure 4-5. This system is designed to condition the gas and vapor streams by continuous selective removal of particulates, condensates, and water vapor, without loss of the gases being measured. The modified system uses a heated

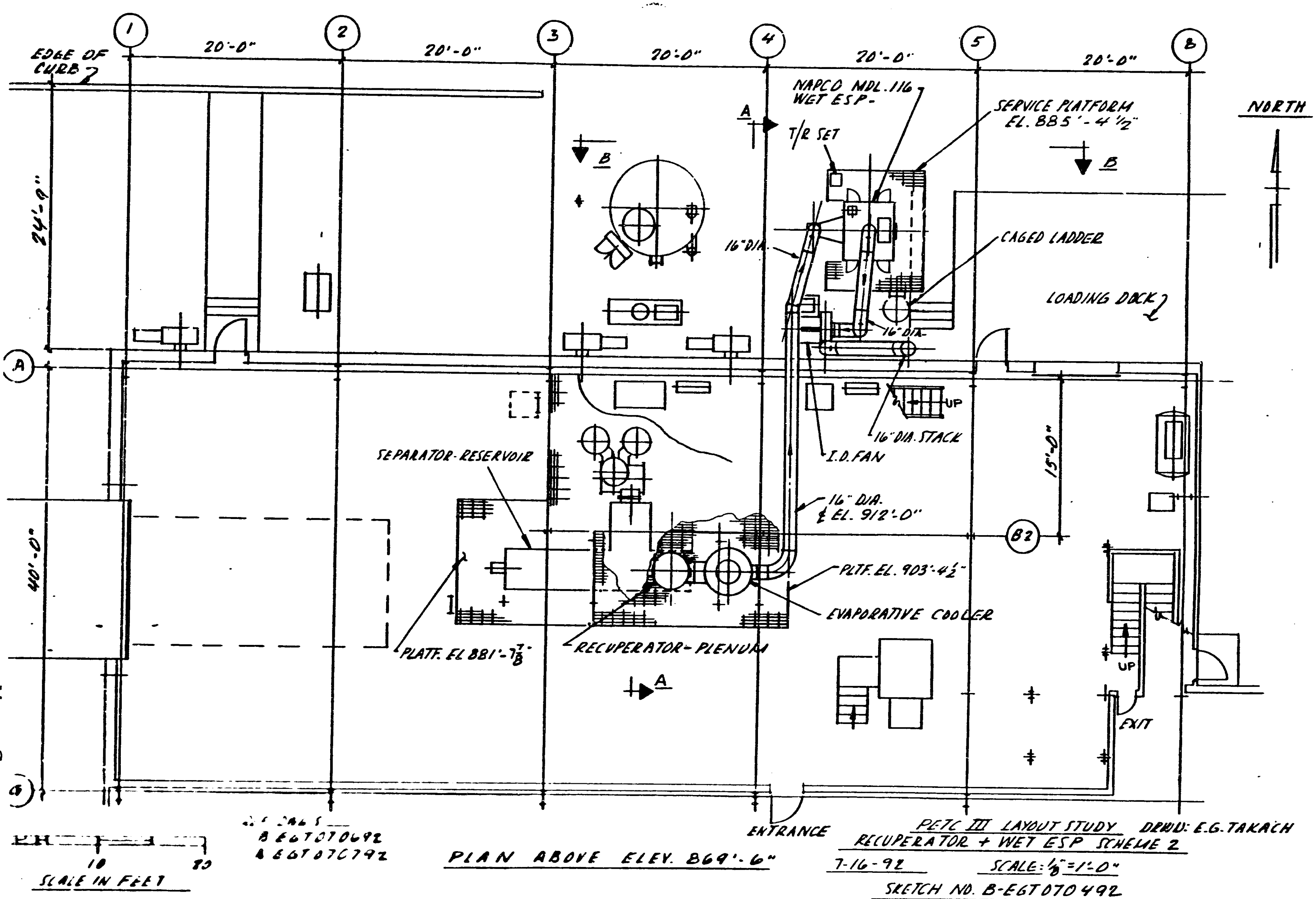


Figure 4-1 Plan Sketch of the Flue Gas Conditioning Subsystem

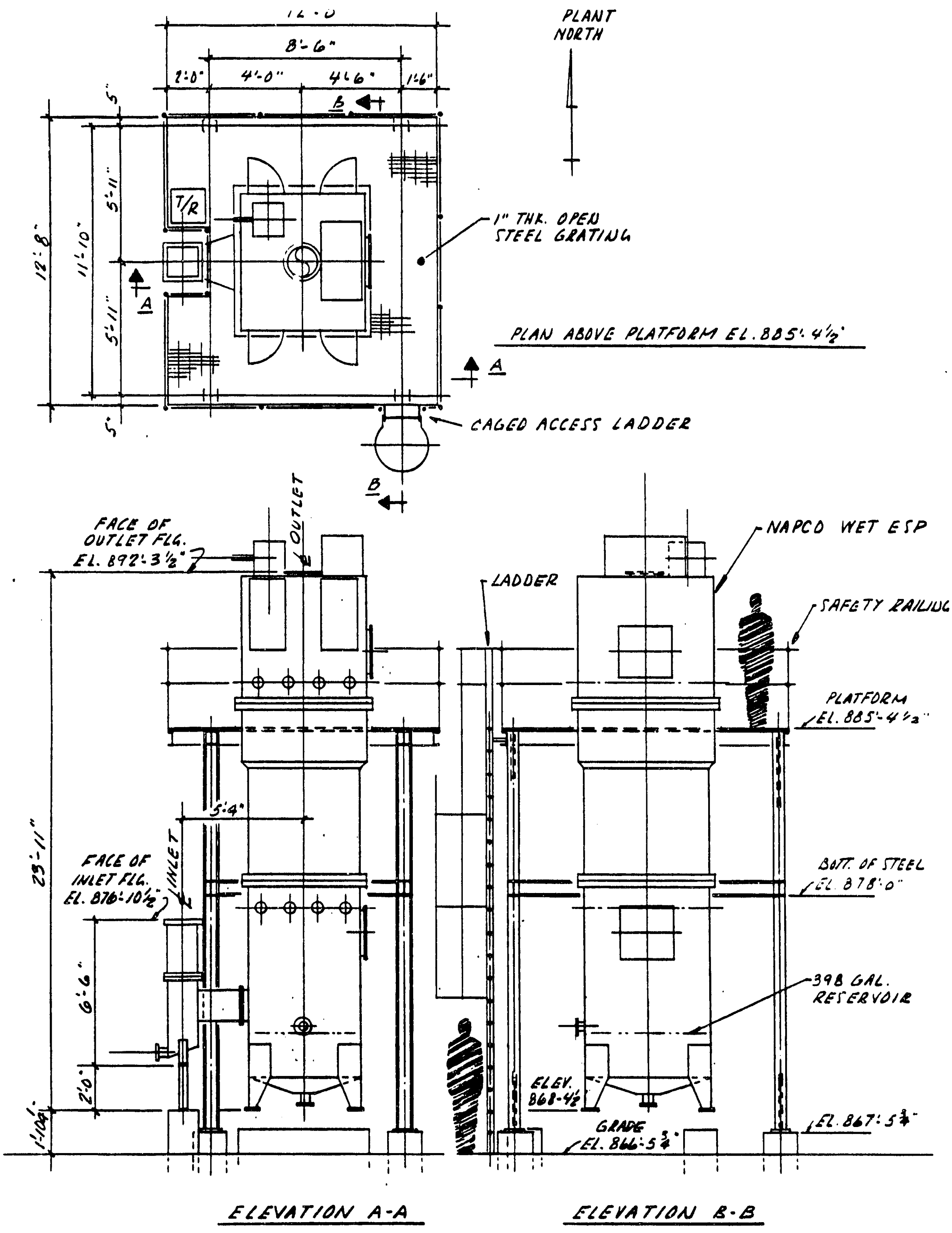


Figure 4-2 Elevation Sketch of the Flue Gas Conditioning Subsystem

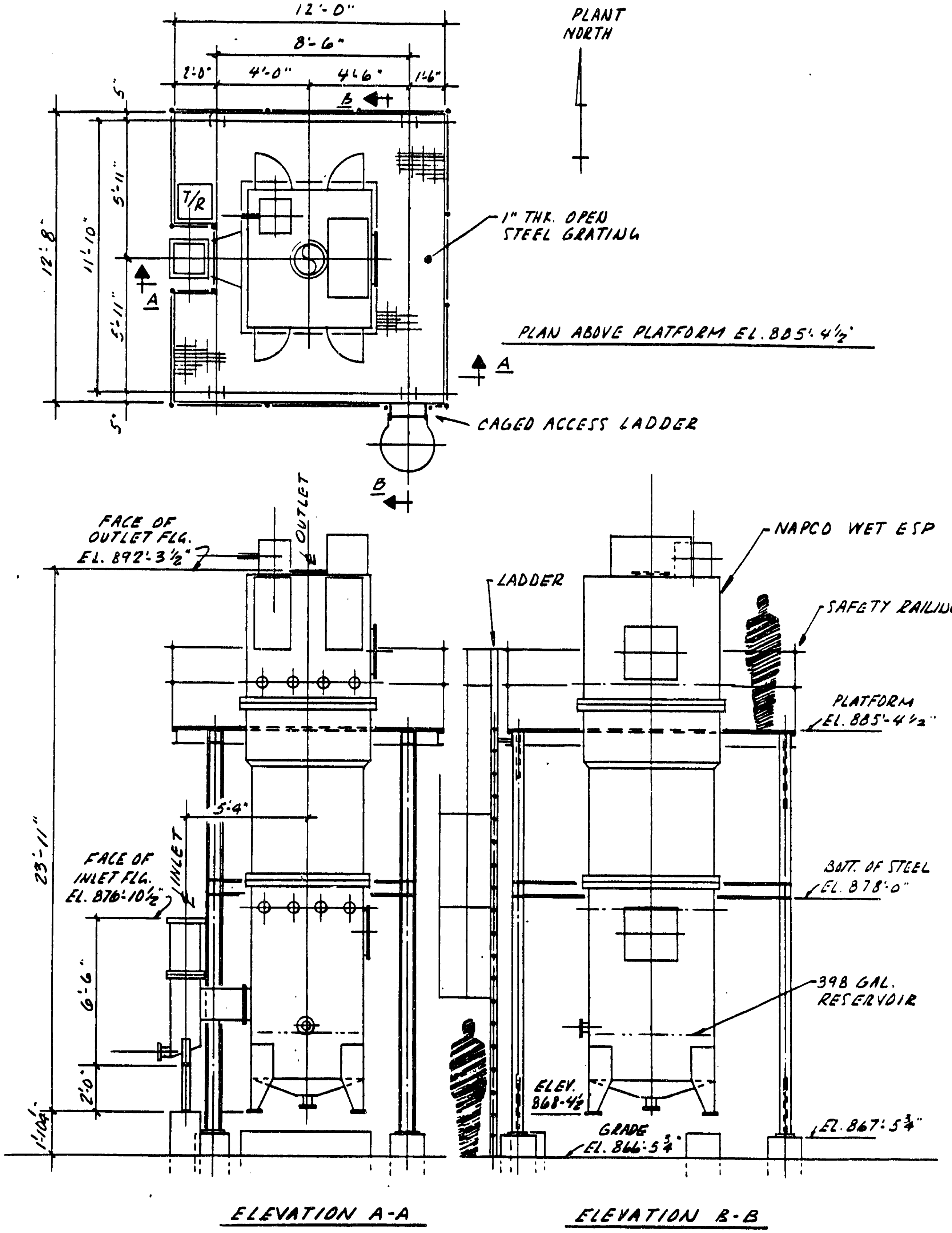


Figure 4-3 Outline Drawing of the Wet ESP

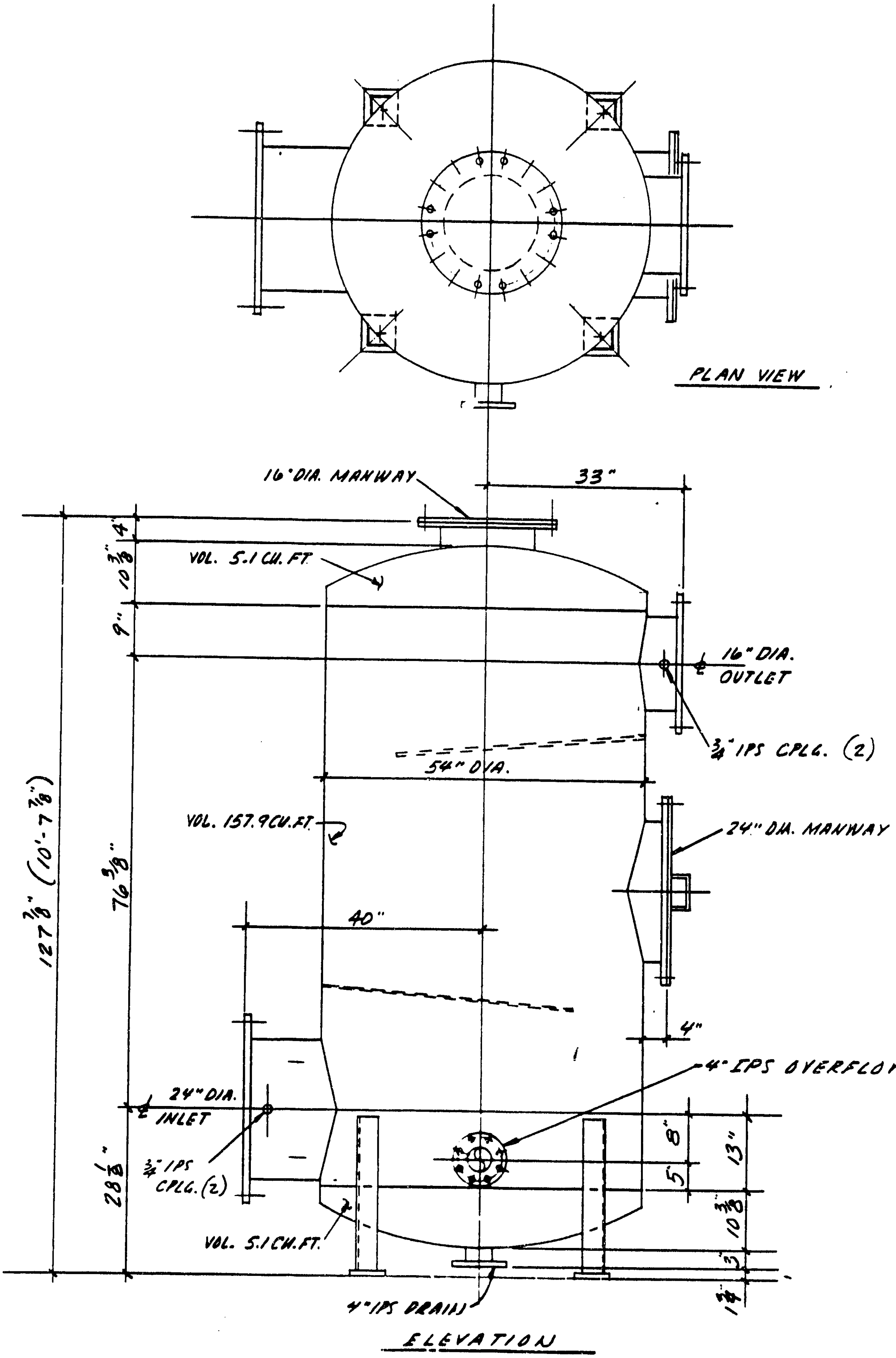


Figure 4-4 Outline Drawing of the Evaporative Cooler

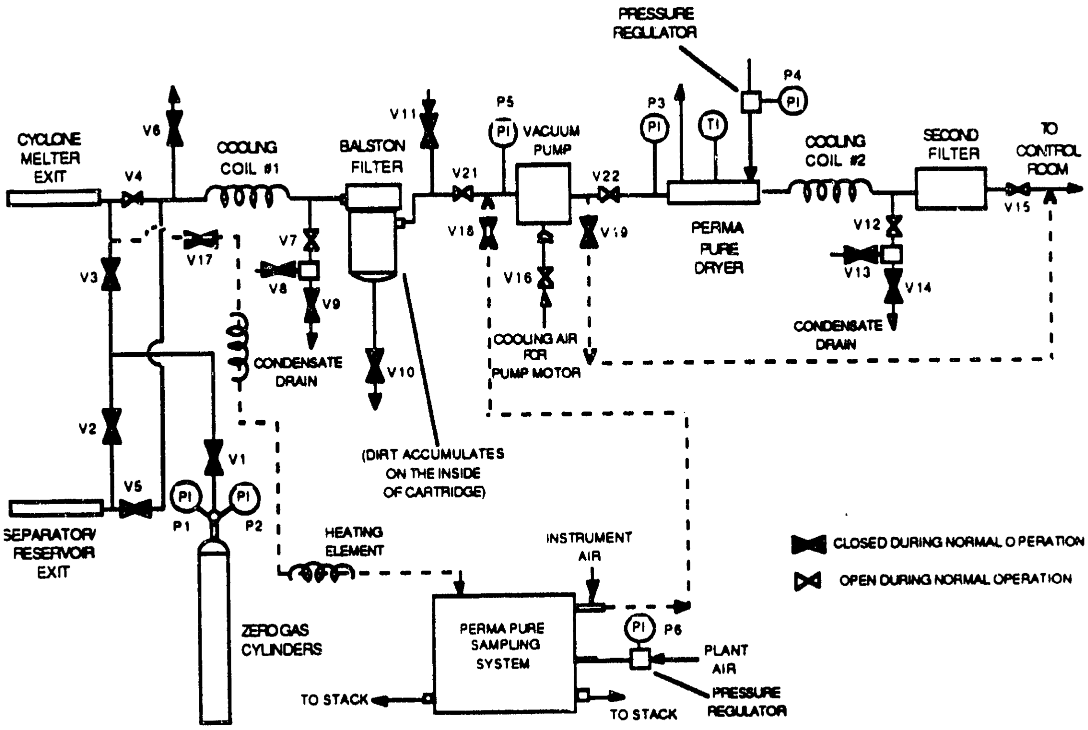


Figure 4-5. Flue Gas Sampling System

sampling line directly to the Perma Pure sampling system and shares the same vacuum pump used with the original system. Because the sample gas has been conditioned by the Perma Pure system, the dryers and filter down steam of the vacuum pump are bypassed.

The Perma Pure system was installed parallel with the original system so that a comparison between the two system can be made. If the Perma Pure system proves to be superior, the original system will be removed.

4.1.3 Component Integration

<u>Control System</u>

New control logic was developed using an updated version of Genesis control software Additional control system hardware (controller boards and power supplies) were also installed in anticipation of the installation of the recuperator and ESP. As-built drawings of the existing control system are being produced or updated to reflect the new configuration.

4.2 Test Operations

Three preliminary coal-fired tests were performed during this period (Test Run Nos. 37, 42, and 45). The primary objectives of the preliminary tests were to obtain baseline information on the melting performance of the candidate waste materials to be processed under the proof-of-concept testing and to characterize flue gas emissions for future installation of supplemental air pollution control equipment. A total of 24 hours of coal-fired process heating operation were accumulated during the test runs. Table 4-1 summarizes the principal test parameters of the tests which were performed. Method 5 analyses were performed for the measurement of particulate emissions during steady state operation of the test runs and was performed by an independent environmental company. NOx, SO_2, O_2, CO_2 and CO measurements were measured by Vortec using an on-line emissions analysis sampling train. A Genesis computer package was used for the data logging of all thermocouple, pressure, and flow measurements made in the course of a typical test run. Manual data logs are also kept for critical process information. Complete data analyses on all of the test runs has not yet been completed. Therefore, the data presented herein should be considered preliminary in nature.

<u>Test No. 37</u>

Test No. 37 examined the melting of an industrial boiler flyash when blended with 30% limestone. The mixture ratio of limestone to flyash was based on the melting characteristics as determined by laboratory crucible melts and previous pilot scale test operations.

The boiler flyash tested contained a large amount of unburned carbon (45% loss on ignition). A Quantitative Chemical Analysis of the flyash feedstock and the vitrified product is shown in Figure 4-2. Early in the test, it appeared that there was a substantial amount of unburned carbon in the glass and in the carryover particulate. Because of this, it was decided to use oxygen enrichment. When the oxygen was introduced, there was an immediate increase in temperature. The natural gas input to the system was decreased and eventually turned off. The unburned carbon in the flyash was sufficient to provide all of the thermal input required to operate the system. Data collected during the test is currently being reduced and will be analyzed to better understand this phenomenon.

Preliminary Test Summary

11-Nov-92

Test Run No	Date	Fuel Type	Combustion Air			Feedstock		Test Length	Glass		Emissions*				Heat Rate	
			Nominal Rate (MM Btu/Hr)	Excess Air (Nominal)	Preheat Temp. (Nominal, °F)	Type	Rate (lb/hr)	Test Duration (hrs.)	Qty Melted (lbs)	Temperature (°F)	NOx (ppmv)	SO2 (ppmv)	CO (ppmv)	Particulates % of Feed	MM Btu/ ton of batch	MM Btu/ ton of glass
29	9/16/91	Natural Gas	3.85	6%	1050	Duquesne 60% utility FA 40% limestone 7% L.O.I.	778	10	7134	2700	264.2	107.5	515.7	2.28	9.90	12.66
30	10/10/91	Natural Gas	4.02	24%	1100	Res Fiberglass 6% L.O.I.	1600	4	4287	2200-2300	NA	NA	47.3	7.77	5.03	5.35
31	4/29/92	Natural Gas	3.691	31.40%	1102	Sewage Sludge Ash 5% L.O.I. 15% Water	961	7.5	3602	2320	168.9	19.78	1309	1.53	7.68	9.60
32	4/29/92	Natural Gas	3.34	45%	1104	MSW Flyash Northeast 7.5% L.O.I. 0.5% Water	818	6	3644	2320	27.2	76.2	28.02	4.2	8.17	8.88
33	4/30/92	Natural Gas	3.542	40%	1103.5	Consumer Waste Cullet	1034	4.5	4160	2310	82.1	4.2	1567.3	0.38	6.85	6.88
34	6/17/92	Natural Gas & Oxygen	3.185	43%	1071	Consumer Waste Cullet	1103	5	1714	2393	1296.9	14.8	127.1	NA	5.78	5.78
37	7/22/92	Coal Char	1.56	6%	1080	Industrial Boiler Flyash HC - Narrows	831	6.5	4875	2500+	264	107	515	2.28%	3.75**	3.75**
42	9/16/92	Coal U. Elkhorn	2.4	10%	1080	Sewer Sludge Ash (Alcasan)	680	6	3250	2500	425	225	112	1.50%	7.05	7.05
45	9/17/92	Coal	1.7	10%	1075	Cullet	980	5	4300	2100	200	130	80	1.00%	3.5	3.5

* Emission data corrected to 3% oxygen, dry gas
** Thermal Input From Waste Feedstock
NA=Not Available

Table 4-1. Summary of Preliminary Coal-Fired Test Operations

Table 4-2 Test 37 Feedstock and Vitrified Product Quantitative Chemical Analysis

Determination	Feedstock Results (Wt.%)	Vitrified Product Results (Wt.%)
K_2O	1.54	1.16
Na_2O	0.31	0.35
Al_2O_3	17.6	23.2
CaO	0.88	30.2
Cr_2O_3	0.019	0.66
Fe_2O_3	3.46	5.56
MgO	0.54	0.84
PbO	0.044	<0.0035
SiO_2	32.5	35.7
SO_3	1.41	0.044
C	37.5	-

The vitrified product melt temperature for this test run was nominally 2700°F. The nominal heat input during the test run was 3.85 million Btu/hr with a feedstock flow rate of 778 lb/hr and an excess air level of 6%. The total uncontrolled particulate emissions amounted to 2.28 % of the total solids feedstock delivered to the CMS. A majority of the carryover from the process was captured in the venturi scrubber located downstream of the reservoir giving a total controlled emission rate of 0.7 % of total solids delivered to the CMS. Table 4-3 shows that the majority (58%) of the particles not captured by the venturi scrubber had an aerodynamic particle size between 10.0-25.0 μm. With the addition of the wet electrostatic precipitator, the carryover of particulates is projected to be less than 0.001 gr/dscf. The NOx, SO_2 and CO levels measured during the test while operating on coal were 264, 107 and 515 ppmv, respectively.

Because of the unexpected high temperatures encountered while firing the boiler flyash with oxygen enrichment, the separator/reservoir refractory sustained some damage. The separator/reservoir was repaired prior to additional testing

Table 4-3 Test 37 Carryover Particulate Size Distribution

Weight Percent	Aerodynamic Particle Size Range (µm)	Percent of Total Mass in Size Range	Cumulative % Less than Stated Size
<1	75.0-100.0	0	100
1	50.0-75.0	1	99
13	25.0-50.0	13	86
58	10.0-25.0	58	28
16	5.0-10.0	16	12
5	2.5-5.0	5	7
6	1.0-2.5	6	1
<1	0.2-1	1	0

Test No. 42

Test Run 42 evaluated the vitrification of an ash generated by the incineration of sewage sludge using a washed Upper Elkhorn as the fuel. This test was conducted in conjunction with a DOE SBIR program to evaluate the use of the CMS as a coal-fired sewer sludge vitrification system. Sewage sludge incinerator ash vitrification represents an additional potential market for coal-fired operation not originally identified. It is estimated that approximately 42 pounds of organic dry solids of wastewater sludge are generated annually per inhabitant. Thus, in the United States, about 4.6 million tons of organic dry solids of wastewater sludge are produced. Of this total, about 4 million dry tons of sewage sludge are generated in U.S. municipal wastewater plants each year. Approximately 25% of the material is currently incinerated. As a result of the incineration of the more than 4 million tons of dry solids, more than 400,000 tons of ash are generated annually which must be disposed of in an environmentally acceptable manner. Municipal sludge ash is normally exempted from regulation as a solid waste. The sewage sludge incinerator flyash with an SiO_2 concentration of 39.5%, Al_2O_3 of 9.3% and CaO of 14.0% was found to melt readily by modest increases in the glass modifier concentrations.

During the test, the CRV was 100% coal-fired with a coal thermal input of approximately 2.4 million Btu/hr while feeding sludge ash at an average rate of 680 lbs/hr Approximately

3300 lbs of ash were melted over the 6 hr test period. The relatively high average heat rate of 7.06 million Btu/ton is due primarily form the low average ash flow rate.

During the period when the EPA Method 5 measurements were made, the feedstock feed rate was 961 lbs/hr and the fuel input requirement for melting amounted to 7.7 million Btu per ton of waste input The excess air during combustion amounted to 31.4 %. The NOx, SO_2 and CO levels during the test run were measured to be 425, 225 and 112 ppmv, respectively. The total uncontrolled particulate carryover is estimated to be 1.5% of the feedstock feed rate. The measured carryover to the stack was 4.3 lbs/hr, or 0.45% of the feedstock feed rate. The chemical analyses of the particulate from the scrubber and the particulate collected in the stack are presented in Table 4-4. Table 4-5 shows that the majority (60%) of the particles not captured by the venturi scrubber had an aerodynamic particle size less than 5.0 µm. With the addition of a wet electrostatic precipitator, it is estimated the stack emissions with typical sewage sludge incinerator ashes will be less than 0.003 gr/dscf.

The glass product appeared fully vitrified and homogeneous. The quantitative chemical analysis of the vitrified product is Shown in Table 4-6.

The TCLP test data is shown in Table 4-7 and indicate that the vitrified product readily passes the leaching test requirements for RCRA metals.

Vortec has been contacted by several municipalities to provide information and cost quotations for a vitrification system which can transform their sludge ash into a value added product. They are being driven to evaluate this alternative because of decreasing landfill space, increasing landfill costs, and local and state regulations. This test was very successful and demonstrated the feasibility of using a coal-fired CMS for this application.

Test No. 45

Test No. 45 evaluated injecting coal, co-axially with the batch, directly into the CRV The primary objective of this test was to evaluate the burning characteristics of the coal (beneficiated Upper Elkhorn seam coal) when injected directly into the CRV and to see if complete burnout of the coal could be obtained prior to interaction with the glass. The analysis for this coal is provided in Table 4-8.

Table 4-4 Test 42 Scrubber and Stack Particulate Quantitative Chemical Analysis

Determination	Scrubber Sediment Results (Wt.%)	Stack Particulate Results (Wt.%)
K_2O	1.75	11.3
Na_2O	0.74	20.2
Ag_2O	0.70	2.68
Al_2O_3	7.16	0.82
BaO	0.10	0.035
CaO	35.3	8.78
Cr_2O_3	1.30	3.49
Fe_2O_3	4.30	1.29
MgO	1.31	0.45
P_2O_5	18.6	8.80
PbO	0.31	2.57
SiO_2	10.8	1.64
SO_3	1.9	29.1
C	30.6	0.16
Cl	0.16	2.20

Table 4-5 Test 42 Carryover Particulate Size Distribution

Weight Percent	Aerodynamic Particle Size Range (µm)	Percent of Total Mass in Size Range	Cumulative % Less than Stated Size
1	75.0-100.0	1	99
4	50.0-75.0	4	95
19	30.0-50.0	19	76
4	20.0-30.0	4	72
5	15.0-20.0	5	67
4	10.0-15.0	4	63
4	5.0-10.0	4	59
13	2.5-5.0	13	46
45	1.0-2.5	44	2
3	0.2-1	3	0

Table 4-6 Test 42 Vitrified Product Quantitative Chemical Analysis

Determination	Vitrified Product Results (Wt.%)
K_2O	1.76
Na_2O	0.70
Ag_2O	0.0067
Al_2O_3	14.1
BaO	0.19
CaO	17.8
Cr_2O_3	0.24
Fe_2O_3	7.63
FeO	4.72
MgO	1.96
P_2O_5	9.28
PbO	0.028
SiO_2	42.9
SO_3	0.01
C	0.003
Cl	0.16

Table 4-7 Test Run 42 TCLP Test Data

Parameter	Method	Unadjusted Result (mg/L)	Adjusted Result (mg/L)	PQL (mg/L)	Regulatory Level (mg/L)
Arsenic	1311	0.15	0.16	0.05	5.0
Barium	6010	0.029	0.032	0.005	100.0
Cadmium	6010	<0.005	<0.005	<0.005	1.0
Chromium	6010	<0.01	<0.01	0.01	5.0
Lead	6010	<0.025	<0.034	0.034	5.0
Mercury	7470	<0.0003	<0.0003	0.0003	0.2
Selenium	6010	<0.05	<0.06	0.06	1.0
Silver	6010	<0.005	<0.006	0.006	5.0

For this test, a glass cullet was used as the feedstock because the oxidation state (color) of the glass gives a good indication of the effectiveness of this injection configuration. During this test, the coal thermal input was 1.7 million Btu/hr with a glass flow of 980 lbs/hr giving a heat rate of 3.5 million Btu/ton. Table 4-9 give the chemical compositions for the feedstock and the vitrified product. The glass color was a light green with steaks of amber and brown. The amber and brown streaks indicate that some reduction of the glass did occur by coal burning in contact with the glass.

After approximately 1 hour of coal-fired testing, oxygen was introduced into the top of the CRV to O_2 enrich the oxidant. The O_2 flow rate was initiated at 100 lb/hr and increased to 205 lb/hr. The air flow into the inlet arms of the CRV combustor was simultaneously decreased to result in the same total O_2 input to the system as there was when only air was used as the oxidant. At this point in time, the resulting concentration of O_2 in the oxidant in the combustor was in the range of 35%. The coal flow rate was held constant and the temperature in the CRV was allowed to increase. The thermocouple reading at the discharge of the CRV combustor increased approximately 300°F in approximately 5 minutes while the temperature at the exit of the cyclone melter increased by only approximately 20°F in the same period. This would appear to indicate that with the introduction of O_2, more of the combustion was occurring in the CRV combustor than

Table 4-8 Analysis of Upper Elkhorn Beneficiated Coal

Proximate Analysis

	As Received	Dry Basis
% Moisture	3.34	xxxx
% Ash	2.03	2.10
% Volatile	34.43	35.62
% Fixed Carbon	60.20	62.28
	100.00	100.00

Ultimate Analysis

	As Received	Dry Basis
% Moisture	3.34	xxxx
% Carbon	80.33	83.11
% Hydrogen	4.95	5.12
% Nitrogen	1.46	1.51
% Sulfur	0.57	0.59
% Ash	2.03	2.10
% Oxygen (Diff)	7.32	7.57

Fusion Temperature of Ash, (°F)

	Reducing	Oxidizing
Initial Deformation	2098	2307
Softening	2200	2451
Hemispherical	2361	2476
Fluid	2490	2590

Table 4-9 Test 45 Feedstock and Vitrified Product Quantitative Chemical Analysis

Determination	Feedstock Results (Wt.%)	Vitrified Product Results (Wt.%)
K_2O	0.10	0.11
Na_2O	13.6	13.4
Al_2O_3	0.41	0.66
BaO	<0.002	0.012
CaO	8.71	8.63
Cr_2O_3	0.0065	0.028
Fe_2O_3	0.47	0.40
FeO	-	0.14
MgO	3.92	3.83
P_2O_5	0.082	0.014
SiO_2	64.0	61.5
SO_3	0.25	0.13
C	0.10	0.004
LOD @110°C	0.24	-
LOI @600°C	0.50	-

when air alone was used as the oxidant. After introduction of the O_2, the color of the glass changed to light green with little or no amber discoloration, thus indicating improved coal combustion with O_2 enrichment.

During the period of oxygen enrichment, the NOx, SOx, and CO concentrations were measure at 200, 130, and 80 ppm respectively. Total uncontrolled particulate emissions were estimated to be approximately 1% of the feedstock feed rate. The emission rate after the wet venturi scrubber was measure to be 0.79 lb/hr or approximately 0.14% of the feedstock feed rate. Table 4-10 shows that the majority (87%) of the particles not captured by the venturi scrubber had an aerodynamic particle size between 75 and 15.0 µm. The carryover particulate was also subjected to computer controlled scanning electron microscopy (CCSEM) analysis to determine its approximate chemical composition. This data is presented in Table 4-11.

Table 4-10 Test 45 Carryover Particulate Size Distribution

Weight Percent	Aerodynamic Particle Size Range (μm)	Percent of Total Mass in Size Range	Cumulative % Less than Stated Size
2	150.0-100.0	2	98
7	75.0-100.0	7	91
21	50.0-75.0	21	70
33	30.0-50.0	33	37
6	20.0-30.0	6	31
16	15.0-20.0	16	15
11	10.0-15.0	11	4
1	5.0-10.0	1	3
1	2.5-5.0	1	2
1	1.0-2.5	1	1
0	0.2-1	0	0

Table 4-11 Test 45 Carryover CCSEM Particle Type Data

Particle Type	Weight Percent
Na/A/K-rich	24.0
Na/S/Ca/K-rich	15.8
Na/S/Cl/K-rich	13.8
Na/Cl-rich	10.4
Ca/S-rich	8.9
Na/S/Cl-rich	8.5
Al-rich	3.0
C-rich	2.4
Cl-rich	2.9
Ca/S/Na-rich	1.9
Na/S-rich	1.6
K/S-rich	1.3
Pb-rich	0.8
Miscellaneous	4.7

4.3 Commercialization Planning

Market studies on hazardous waste vitrification and waste recycling were obtained and are being reviewed. Discussions with potential sources of support for preparation of a business plan were initiated. A strategy for securing capital support for commercialization of the CMS technology is being developed.

4.4 Project Management

The third quarterly technical progress report and test plan were completed and submitted to DOE. Additionally, a construction management plan was developed for the installation of the wet ESP to ensure that schedule and cost goals are met. A paper outlining this development program was prepared and presented at the annual PETC contractors review conference held in Pittsburgh, PA.

5.0 PLANNED ACTIVITIES

5.1 Task - 1 Design, Fabricate, and Integrate Components

The fabrication of the wet ESP is expected to be completed during the next reporting period. Modifications required for the installation, equipment footers, piping and ducting, and wiring, are also expected to be completed. Final integration of the complete flue gas clean-up system is expected to be completed during the first quarter of CY 93.

The recuperator vendor should be released to begin fabrication of the heat recovery subsystem during the first quarter of CY 93 with installation occurring during the second quarter of CY 93.

A bid evaluation for the fabrication of the evaporative cooler will be conducted and a qualified vendor will be selected. It is expected that the vendor will be released to begin fabrication during the next quarter.

The design of an exhaust plenum which acts as a transition between the recuperator and the evaporative cooler will be completed during the next quarter. It is expected that the plenum will be fabricated during the first quarter of CY 93.

5.2 Task 2 - Perform Preliminary System Tests

During the next reporting period, the test system is scheduled to be modified with the addition of the wet ESP. During this period no additional pilot-scale testing is anticipated. Testing is planned to resume in the first quarter of 1993.

Crucible melts of an anthracite based industrial waste will be performed to establish the loss on ignition (L.O.I) and the melting characteristics of the ash with various glass forming additives. Glass samples will be sent out for laboratory analysis to determine the feasibility of forming a glass from this waste. This waste has been identified as a potential near term application of the CMS, and the waste producer is funding this feasibility analysis as well as follow-on pilot-scale tests.

5.3 Task 4 - Evaluate Economics/Prepare Commercialization Plan

Evaluation on potential new markets for the CMS technology will continue. Additionally, the commercial system designs will be refined leading to more accurate cost estimates. These data will be integrated into the commercialization plan as they become available.

6.0 SUMMARY

The design modifications are proceeding as planned. A purchase order for the fabrication of the APC system was issued and fabrication is underway. The designs for the installation of the APC have been completed and preliminary site work has begun. Release for fabrication of the recuperator are being held in abeyance pending release of FY93 funding allocation.

Preliminary coal-fired tests with various feedstock materials were completed. A total of three preliminary coal-fired test runs totaling 24 hours of melting operations were performed during this reporting period.

During the next reporting period, no additional pilot-scale tests are planned because of the ESP installation work.

Significant progress has been made in the commercialization planning task. Cost sharing support for the test operations is being provided by several waste generators and preliminary plans are being developed for commercial demonstration systems.

7.0 REPORT DISTRIBUTION LIST

The report distribution list as specified in the contract is as follows:

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