COPY NO. _____

DEVELOPMENT OF A COAL-FIRED COMBUSTION SYSTEM FOR INDUSTRIAL PROCESS HEATING APPLICATIONS

PHASE III FINAL REPORT

CONTRACT DE-AC22-91PC91161

NOVEMBER 1992 TO DECEMBER 1994

PREPARED FOR

U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER

PREPARED BY

VORTEC CORPORATION
3770 RIDGE PIKE
COLLEGEVILLE, PA 19426

RECEIVED
USDOE/PETC
95 SEP 32 AM 10:41
ACQUISITION & ASSISTANCE DIV.

September 26, 1995

CLEARED BY
PATENT COUNSEL

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DOE/PC/91161--T13

COPY NO. _____

DEVELOPMENT OF A COAL-FIRED COMBUSTION SYSTEM FOR INDUSTRIAL PROCESS HEATING APPLICATIONS

PHASE III FINAL REPORT

CONTRACT DE-AC22-91PC91161

NOVEMBER 1992 TO DECEMBER 1994

PREPARED FOR

U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER

PREPARED BY

VORTEC CORPORATION
3770 RIDGE PIKE
COLLEGEVILLE, PA 19426

September 26, 1995

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

Vortec Corporation and the Department of Energy, Pittsburgh Energy Technology Center (PETC), have completed a three phase research and development program which has resulted in the development and commercialization of a Cyclone Melting System (CMS™), capable of being fueled by pulverized coal, natural gas, and other solid, gaseous, or liquid fuels, for the vitrification of industrial wastes.

Phase I of the program, initiated in 1987 and completed in 1989, addressed the technical and economic feasibility of the process via the design, fabrication, installation, and feasibility testing of a nominal 15 ton/day system. Phase II of the program, initiated in 1989 and completed in 1990, implemented design improvements to critical components and addressed the performance of the process using several different feedstocks. The Phase III research effort, which began in 1991 and culminated in a 105 hour demonstration test in September 1994, focused on the development of a process heater system to be used for producing value added glass products from the vitrification of boiler/incinerator ashes and industrial wastes. The primary objective of the Phase III project was 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 for successful commercialization.

Ninety-seven major tests were successfully performed with a nominal 15 ton/day advanced combustion and melting system (CMS™) since its construction in 1989, as shown in Table 1-1. The system has been operated for more than 835 hours, processing more than 457,500 lbs of the glass batch and waste materials listed in Table 1-2. Seventy-five tests were performed during the Phase III performance period with 22 of those supported by the DOE/PETC program. Phase III culminated with an extended duration demonstration test of the 15 ton/day CMS™.

The demonstration test consisted of one test run (listed as Test No. 93 in Table 1-1), with a duration of 105 hours, approximately one-half (46 hours) performed with coal as the primary fuel source (70% to 100%), the other half with natural gas. Approximately 50 hours of melting operation were performed vitrifying approximately 50,000 lbs of coal-fired utility boiler flyash/dolomite mixture, producing a fully-reacted vitrified product. The flyash, supplied by Pennsylvania Electric Company (PENELEC), contained approximately 4% by weight of carbon. The unburned carbon in the flyash/dolomite mixture (60%/40% by weight) provided approximately 10% of the total energy input to the vitrification system.

Table 1-1
Vortec Subscale CMS™ Test Operations Summary

VORTEC PILOT SCALE CMS - TEST OPERATIONS SUMMARY

Test Run Number	Date	Fuel Type	Oxidant	Feedstock	Test Duration (hrs.)	Batch Quantity Melted (lbs)
1	5/17/89	Nat. Gas	Air	Bassichis GL-70 Cullet	1.0	1,000
2	5/31/89	Nat. Gas	Air	Bassichis GL-70 Cullet	4.0	3,680
3	6/14/89	Nat. Gas	Air	Bassichis GL-70 Cullet	6.0	7,873
4	6/22/89	Nat. Gas	Air	Potter's D-Dust	4.5	5,016
5	6/29/89	Nat. Gas	Air	Potter's D-Dust	5.5	8,340
6	7/11/89	Nat. Gas	Air	Potter's D-Dust	6.0	9,148
7	7/18/89	Nat. Gas	Air	Potter's D-Dust	8.0	9,148
8	8/29/89	Nat. Gas & Coal	Air	Bassichis GL-70 Cullet	5.5	5,700
9	9/7/89	Nat. Gas & Coal	Air	Bassichis GL-70 Cullet	6.5	4,200
10	9/14/89	Nat. Gas & Coal	Air	Bassichis GL-70 Cullet	9.0	5,653
11	9/28/89	Nat. Gas & Coal	Air	Bassichis GL-70 Cullet	4.0	7,300
12	10/25/89	Nat. Gas & Coal	Air	Fiberglass Blowing Wool	2.8	2,000
13	10/30/89	Nat. Gas	Air	Fiberglass Blowing Wool	8.0	3,350
14	11/21/89	Nat. Gas	Air	Bassichis GL-70 Cullet & Fiberglass Blowing Wool	4.5	4,360
15	12/7/89	Nat. Gas & Coal	Air	Ground Fiberglass Blowing Wool	7.5	640
16	12/14/89	Nat. Gas & Coal	Air	Blowing Wool	3.5	0
17	1/17/90	Nat. Gas	Air	Potters Roth Bros	5.0	3,870

Table 1-1
Vortec Subscale CMS™ Test Operations Summary
(Continued)

VORTEC PILOT SCALE CMS - TEST OPERATIONS SUMMARY						
Test Run Number	Date	Fuel Type	Oxidant	Feedstock	Test Duration (hrs.)	Batch Quantity Melted (lbs)
18	2/13/90	Nat. Gas & Coal	Air	Duquesne Flyash	2.8	1,262
19	2/20/90	Nat. Gas & Coal	Air	Flyash & GL-70 cullet	4.5	4,215
20	3/15/90	Nat. Gas & Coal	Air	Flyash	2.3	2,000
21	11/13/90 11/16/90	Nat. Gas & Coal	Air	Soda Ash& Silica Sand	60.0	8,335
22A	12/17/90 thru 12/18/90	Nat. Gas	Air	Blowing Wool	17.5	622
22B	12/17/90 thru 12/18/90	Nat. Gas	Air	Blowing Wool	x	x
23	1/21/91	Nat. Gas	Air	Blowing Wool	8.0	700
24	4/24/91 thru 4/26/91	Nat. Gas & Coal	Air	Wool/Board	32.0	3,750
25	5/23/91	Nat. Gas & Coal	Air	Foil board	5.3	2,500
26.1	6/26/91	Nat. Gas	Air	Duquesne 70% utility FA 30% limestone	7.5	5,865
26.2	6/26/91 thru 6/27/91	Nat. Gas	Air	Duquesne 70% utility FA 30% limestone	3.0	x
27	8/21/91	Nat. Gas	Air	Duquesne 60% utility FA 40% limestone	8.0	8,300
28	SEPARATOR / RESERVOIR MELT OUT					
29	9/16/91	Nat. Gas	Air	Duquesne 60% utility FA 40% limestone	10.0	7,134
30	10/10/91	Nat. Gas	Air	Res Fiberglass	4.0	668
31	4/29/92	Nat. Gas	Air	Sewage Sludge Ash	7.5	3,602
32	4/29/92	Nat. Gas	Air	MSW Flyash Northeast	6.0	3,644

Table 1-1
Vortec Subscale CMS™ Test Operations Summary (Continued)

VORTEC PILOT SCALE CMS - TEST OPERATIONS SUMMARY

Test Run Number	Date	Fuel Type	Oxidant	Feedstock	Test Duration (hrs.)	Batch Quantity Melted (lbs)
33	4/30/92	Nat. Gas	Air	Consumer Waste Cullet	5.5	4,160
34	6/17/92	Nat. Gas & Oxy	Oxygen	Consumer Waste Cullet	5.0	1,714
35	6/17/92	Nat. Gas	Air	Textile Fiber-glass Waste	4.0	4,800
36.1 36.2	6/18/92	Nat. Gas	Air	Surrogate Soil Site-4	6.0	4,818
37	7/22/92	Coal Char	Air	Industrial Boiler Flyash HC - Narrows	9.0	4,908
38	7/22/92	Nat. Gas	Air	MSW Incinerator Ash (RWS)	2.0	1,904
39	CANCELLED					
40	7/23/92	Nat. Gas	Air	Waste Fiberglass		450 (Unisol @ 25lb/2min)
41	9/15/92 thru 9/16/92	Nat. Gas	Air	Waste Fiberglass	8.5	4,400
42	9/16/92	Nat. Gas & Coal	Air	Alcosan Sewage Sludge Ash	6.8	3,252
43	9/16/92 thru 9/17/92	Nat. Gas	Air	Lead Reinjection w/ Glass Cullet	3.8	3,500
44	9/17/92	Nat. Gas	Air	Lead Reinjection w/ Canadian MSW Flyash	1.0	654
45	9/17/92	Coal	Air	Glass Cullet	7.3	4,232
46	12/7/92 thru 12/9/92	Nat. Gas	Air	Vetrotex Waste Fiber Glass	43.5	14,270
47	1/6/93	Nat. Gas	Air	Plate Glass Cullet	11.0	10,450
48	12/9/92	Nat. Gas	Air	EPA Site 04 Slurry Sys. Test	2.0	0
49	CANCELLED					

Table 1-1
Vortec Subscale CMS™ Test Operations Summary
(Continued)

VORTEC PILOT SCALE CMS - TEST OPERATIONS SUMMARY

Test Run Number	Date	Fuel Type	Oxidant	Feedstock	Test Duration (hrs.)	Batch Quantity Melted (lbs)
50	2/5/93 2/6/93	Nat. Gas & Coal	Air	HC Flyash w/ swarf	1.0	700
51	3/8/93 3/9/93	Nat. Gas	Air	RGR Container Cullet	25.0	22,500
52	3/9/93 3/10/93	Nat. Gas	Air	RGR Vetrotex Textile Fiber	14.0	12,600
53	4/6/93	Nat. Gas	Air	CertainTeed Waste Fiberglass	8.0	2,400
54	4/7/93	Nat. Gas	Air	SITE 04 Slurry Sys. Test	1.5	900
55	5/4/93	Nat. Gas	Air	Ormet Surrogate Potliners Anthracite Mixed 10 % by weight	10.0	1,820
56	CANCELLED					
57	5/4/93 5/5/93	Nat. Gas	Air	METC Surrogate Soil	3.0	1,950
58	5/5/93	Nat. Gas	Air	SITE 04	7.0	2,100
59	5/7/93	Nat. Gas	Air	CertainTeed Fiberglass Acoustical Board	3.0	3,000
60	6/14/93	Nat. Gas	Air	Ben Franklin 20% Virgin & 80% Virgin	19.0	15,200
61a	6/15/93	Nat. Gas	Air	METC Contaminated Soil	7.0	3,000
61b	6/15/93	Nat. Gas	Air	METC Contaminated Soil	4.0	2,000
62	6/16/93	Nat. Gas	Air	Ormet SPL	3.0	918
63	7/13/93 to 7/15/93	Nat. Gas	Air	Hanford Simulate Dry & Liquid	9.5	5,800
64	7/20/93	Nat. Gas	Air	Utility Metal Soda Ash, Zn Sulfate, Cu Carb.,Ni Carb.	3.5	3,000
65	7/20/93	Nat. Gas	Air	Utility Metal Soda Ash, Cu Carbonate	2.0	1,500

Table 1-1
Vortec Subscale CMS™ Test Operations Summary
(Continued)

VORTEC PILOT SCALE CMS - TEST OPERATIONS SUMMARY

Test Run Number	Date	Fuel Type	Oxidant	Feedstock	Test Duration (hrs.)	Batch Quantity Melted (lbs)
66	7/21/93	Nat. Gas	Air	Utility Metal Soda Ash, Ni Carbonate	4.5	1,400
67	7/21/93	Nat. Gas	Air	Utility Metal Soda Ash, Zn Sulfate	3.5	2,500
68	8/17/93	Nat. Gas	Air	Ormet SPL	3.0	700
69	8/18/93	Nat. Gas	Air	Ormet SPL	4.0	750
70	8/19/93	Nat. Gas	Air	Ormet SPL	3.0	700
71	8/19/93	Nat. Gas	Air	Hoechst Celanese	2.8	900
72	9/14/93	Nat. Gas	Air	CertainTeed Fiberglass Acoustical Brd, Sludge, Paper	11.0	8,000
73	28-Sep to 9/29/93	Nat. Gas	Air	Ferro Soft & Hard Frit, Borax	21.0	5,500
74	12/6/93	Nat. Gas	Air	System Flush Cullet & Soda Ash	5.0	4,000
75	12/7/93	Nat. Gas	Air	TSCA RWS Flyash & NE MSWI Flyash	10.0	5,116
76	12/8/93	Nat. Gas	Air	TSCA RWS Flyash & NE MSWI Flyash	9.5	4,872
77	12/9/93	Nat. Gas	Air	Ormet SPL, Limestone, Cullet, Sand	4.5	2,700
78	1/11/94 1/12/94	Nat. Gas	Air	Batch feed testing Duquesne Light & Limestone	14.0	3,000
79	4/12/94	Nat. Gas	Air	50% Container Batch, 50% Container Cullet	20.5	16,500
80	5/17/94	Nat. Gas	Air	Flint Container Cullet	4.0	4,000
81	5/18/94	Nat. Gas	Air	50% Container Batch, 50% Container Cullet	11.6	8,400
82	5/19/94	Nat. Gas	Air	Sodium Silicate Batch	8.0	3,000

Table 1-1
Vortec Subscale CMS™ Test Operations Summary

VORTEC PILOT SCALE CMS - TEST OPERATIONS SUMMARY

Test Run Number	Date	Fuel Type	Oxidant	Feedstock	Test Duration (hrs.)	Batch Quantity Melted (lbs)
83	6/7/94	Nat. Gas	Air	ASR Ash	2.7	1,250
84	6/7/94	Nat. Gas	Air	60% Penelec Ash 40% Dolomite	4.0	4,000
85	6/8/94	Nat. Gas	Air	74% Soil, 15% Soda Ash, 11% Limestone	7.0	7,000
86	6/9/94	Nat. Gas	Air	74% Soil, 15% Soda Ash, 11% Limestone	7.5	7,000
87	7/20/94	Nat. Gas	Air	ASR Ash	6.5	3,900
88	7/20/94	Nat. Gas	Air	ASR Ash + 25% EAF Dust	5.0	2,150
89	7/20/94	Nat. Gas	Air	ASR Ash + 35% EAF Dust	6.0	1,600
90	7/21/94	Nat. Gas	Air	Soil / Carryover Reinjection	7.5	6,900
91	8/11/94	Coal	Air	60% Penelec Ash, 40% Dolomite	3.0	1,250
92	8/11/94	Coal	Air	None	6.0	0
93	9/12/94 to 9/16/94	Coal & Nat. Gas	Air	60% Penelec Ash, 40% Dolomite	105.0	50,000
94	10/5/94	Nat. Gas	Air	Simulated Soil	6.5	5,000
95	10/6/94	Nat. Gas	Air	Simulated Soil	6.5	6,300
96	10/25/94	Nat. Gas	Air	Waste Fiber Glass	7.0	4,500
97	10/25/94	Nat. Gas	Air	Waste Fiber Glass	2.5	2,300
98	10/26/94	Nat. Gas	Oxygen	Waste Fiber Glass	6.0	4,200
99	10/26/94	Nat. Gas	Oxygen	Waste Fiber Glass	2.0	1,250
100		Nat. Gas	Air	Duquesne 70% utility FA 30% limestone		
TOTALS					835.8	457,513

Table 1-2
Materials Melted in Vortec's 15 ton/day CMS™ Test Facility

Waste Post Consumer Glass
Industry Waste Glass Powder
Insulation Fiberglass Blanket Manufacturing Waste
Insulation Fiberglass Board Manufacturing Waste
Fiberglass Acoustical Board Manufacturing Waste
Waste Blowing Wool
Hazardous Metals Recycling Baghouse Dust
Electric Utility Coal-fired Boiler Flyash
Industrial Coal-fired Boiler Flyash
Soda-Lime-Silica Glass Raw Materials
Sewage Sludge Incinerator Ash
Municipal Solid Waste Incinerator Flyash
Municipal Solid Waste Incinerator Combined Ash
Textile Fiberglass Manufacturing Waste
Textile Fiberglass Manufacturing Raw Materials
Surrogates for Soils (Dry) Contaminated with RCRA Metals
Surrogates for Soils (Slurry) Contaminated with RCRA Metals
Surrogates for Soils with Low Level Radioactive and RCRA Metals Contaminants
Spent Potliner from Aluminum Manufacturing
Surrogates for High Sodium Content, Low Level Radioactive Tank Waste
Surrogates for Metals Plating Industry Waste
Surrogate for TSCA Incinerator Ash
Sodium Silicate Glass Raw Materials
Ash from Automobile Shredder Residue Gasifier
Automobile Shredder Residue Gasifier Ash Mixed with Electric Arc Furnace (EAF) Dust

The test demonstrated the commercial viability of the CMS™ for the vitrification of industrial wastes by producing a consistent vitrified product from coal-fired boiler flyash over an extended duration. It also provided data useful for the design of refractories and flue gas conditioning subsystems for commercial systems.

Based on the results of tests conducted under this R&D program, Vortec has been able to assess the potential markets for the technology. The most promising markets are related to the production of glass products from industrial wastes and the remediation of wastes containing hazardous and low level radioactive contaminants. The primary advantages of the CMS™ technology relative to current technologies are its ability to rapidly melt inorganic constituents in feedstock using a variety of fuels and efficiently oxidize organic constituents which could otherwise be hazardous pollutants. The rapid melting capability is provided by the efficient heating of feedstock in suspension with combustion gases in the process. As a result, the high temperature components comprising the process are smaller in physical size than conventional melting components and thus have lower structural heat losses. This results in higher thermal efficiencies and lower capital and operating costs.

As a result of the development efforts, the technology is now being commercially implemented. The following is a summary of several commercial projects.

Recycling of Industrial Waste

Vortec has negotiated a sales & licensing agreement with Ormet Primary Aluminum for the construction of a CMS™ based spent potliner vitrification process at Ormet's Hannibal, Ohio, aluminum reduction plant. Spent potliner (SPL) is generated during the production of aluminum using the Hall-Heroult Process, which is currently used in all primary aluminum reduction operations. In removing the liner from the pot, the insulating bricks and pot liner itself are often mixed or co-mingled, resulting in a hazardous waste which consists of a mixture of the carbon based liner, barrier brick, and the insulation brick. Carbon liners can be anthracite or graphite based. The CMS technology has the advantage, relative to conventional technologies, of being able to process the entire mixture, oxidizing the carbon in the liner and rapidly melting the refractory (brick) material to produce an oxidized glass frit. The ORMET system will process approximately 34 tons/day of spent potliner producing a glass frit which will be sold to a glass manufacturer for use as an additive to other glass making ingredients. The total investment in the process is expected to be approximately $8 million, inclusive of engineering and design, equipment for all major and support systems, site modifications, construction, and start-up operations. Total processing cost is anticipated to be less than $100/ton. Ormet expects to sell the glass frit for $10 to $30/ton. It currently costs Ormet approximately $350/ton to dispose of their potliner. Therefore, a net savings on the order of $270/ton will be realized through vitrification with the CMS™ technology. This provides a payback on capital investment of less than 3 years.

Remediation of Radioactive & Hazardous Wastes

Vortec has also prepared a commercialization/business plan for the construction and operation of glass/ceramic tile manufacturing plants using coal-fired boiler flyash and/or other waste as the feedstock. A strategic alliance has been formed with Welko, a world renowned tile equipment manufacturer. The cost of raw materials for existing clay-based ceramic tile manufacturing represents from 15% to 35% of the cost of manufacturing. The use of waste materials as a feedstock has the potential for not just reducing the raw material costs but providing a source of income in terms of tipping fees for some wastes. Manufacturing cost savings of 25% are estimated for a CMS™ based ceramic tile manufacturing process relative to existing clay-based manufacturing operations. Coal-fired boiler flyash represents a unique opportunity for this process application. First, the oxide constituents of coal ash are essentially the same as many commercial glasses. Second, there are essentially unlimited supplies of the feedstock. Third, it is possible to receive a tipping fee for the feedstock. Fourth, the ash can serve as an energy source for the process. Finally, the recycling of residual and industrial waste materials will alleviate a substantial number of environmental problems associated with landfilling.

Vortec has a contract with DOE/METC for the construction and operation of a 36 ton/day CMS™ field demonstration process for remediation of soils and other wastes containing hazardous and radioactive constituents at DOE's Paducah Gaseous Diffusion Plant in Paducah, Kentucky. The primary advantages of the CMS™ technology relative to competing technologies, primarily joule-heated melters and plasma arc melters, are its ability to cost effectively vitrify large volumes of waste (several hundred tons/day with a single unit) and efficiently destroy hazardous organic constituents in the waste. Additionally, the CMS™ technology can produce a homogeneous glass product from wastes containing higher concentrations of iron and other metals which tend to form immiscible layers in pool type melters. Processing costs with the CMS™ technology are expected to be in the range from $100 to $200 per ton compared to $500 to $1000 per ton for competing technologies.

Commercial Glass Melting and Waste Glass Recycling

Vortec has also formed strategic alliances with major container and fiber glass manufacturers to commercialize the CMS™ technology for these applications. Continued commercial development in the areas of oxy-fuel firing and waste fiberglass recycling will be supported by Vortec glass industry partners. Significant energy savings in container glass and fiber glass manufacturing are projected.

Commercialization of the CMS™ technology in the glass industry for waste glass recycling and primary glass melting provides the potential for melting energy savings of more than 20 trillion Btu/yr (>30%), energy cost savings of over $70 million/yr, and total manufacturing cost savings of over $300 million/yr.

This report provides a detailed description of the activities and accomplishments of Phase III of the program performed under Contract No. DE-AC22-91PC91161.

2.0 INTRODUCTION

The Department of Energy, Pittsburgh Energy Technology Center (PETC), has implemented a number of advanced combustion research projects intended to expand the use of coal in boilers, furnaces, and industrial process heaters in an environmentally and economically sound manner. 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 Phase III development contract DE-AC22-91PC91161 for a "Coal-Fired Combustion System for Industrial Process Heating Applications" is a project funded under the DOE/PETC advanced combustion program.

The effective start date of the Phase III contract was September 3, 1991. The contract period of performance was 39 months. This report provides a detailed description of the objectives, accomplishments, results, and conclusions of the Phase III effort in addition to summaries of the program objectives and accomplishments of Phases I and II.

2.1 PROGRAM OBJECTIVES

The current contract represents the third phase of a three-phase program to develop an advanced industrial process heater capable of using pulverized coal or coal-derived fuels as the primary fuel for the melting of glass and vitrification of waste materials.

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. The objective was to be accomplished via both analytical and experimental research. The primary objective of Phase II was to improve the performance of the primary components and demonstrate the effective operation of a subscale process heater system. The primary objective of the Phase III project was to develop and integrate all the subscale system components, from fuel through total system controls, and then test the complete system in order to evaluate its potential marketability for the vitrification of boiler and incinerator ashes and other industrial wastes.

2.2 PROGRAM STATUS

Phase I of the program, initiated in March 1987 and completed in September 1989, 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. 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 were also performed. During Phase I-B, a 3 to 5 x 10^6 Btu/hr coal-fired CMS™ test loop capable of melting nominally 15 tons/day of material was designed and installed at Vortec's high temperature process test facility in Harmarville, PA. Eleven major tests, totaling approximately 60 hours of operation, were performed on the critical components to validate the feasibility of the Vortec process heater for glass melting with coal as the primary fuel. 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.

Phase II of the program, initiated in October 1989 and completed in December 1990, implemented design improvements to critical components and addressed the performance of the process using several different feedstocks. The impact of coal ash on glass production quality was assessed and the melting of more complex glasses was evaluated during this phase. Additionally, Vortec evaluated several different markets, particularly in the areas of waste material recycling, in which the Vortec process heater system could 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. Overall, ten major CMS™ tests were performed in Phase II melting over 30,000 lbs of glass and other industrial waste materials.

The Phase III research effort, which began in September 1991, focused on the development of a process heater system to be used for producing value added glass products from the vitrification of boiler/incinerator ashes and industrial wastes. Potential end uses of the glass products include glass/ceramic tiles, 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. The primary objective of the Phase III project was 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 technical and economic potential. The Phase III effort culminated with an extended duration demonstration test of the integrated subscale CMS™ in September 1994.

2.3 PROCESS DESCRIPTION

Vortec's coal-fired process heater system, the CMS™, is unique in several important aspects:

1. The capital cost is significantly lower than conventional gas/oil-fired and electric furnaces;
2. The thermal efficiency is significantly higher than conventional gas/oil-fired melting furnaces;
3. It can satisfy projected future emission requirements for NO_x, SO_x and particulates; and
4. It has a degree of operational flexibility unmatched by conventional fossil fuel-fired glass melting or mineral wool systems. Unique capabilities include multi-fuel use (including coal, coal slurry, petro-coke, oil and gas), rapid product changeover, and rapid startup/shutdown.

An artist rendering of the basic CMS™ concept is shown in Figure 2.3-1. The primary components of the CMS™ are a counter-rotating vortex (CRV) combustor and a cyclone melter. Coal combustion and in-flight suspension preheating of the batch ingredients take place in a CRV combustor. The ash, coal and other feedstock materials are introduced into the combustor through an injector assembly and are rapidly heated in the flame zone. Typical ratios of coal/feedstock are in the range of 1/5 to 1/10. Any unburned carbonaceous materials and organics in the feedstock are rapidly volatilized and oxidized along with the fuel. 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 combustor. However, 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. NO_x emissions have been demonstrated in a pilot scale CMS™ to be typically less than 200 ppm. On a per unit

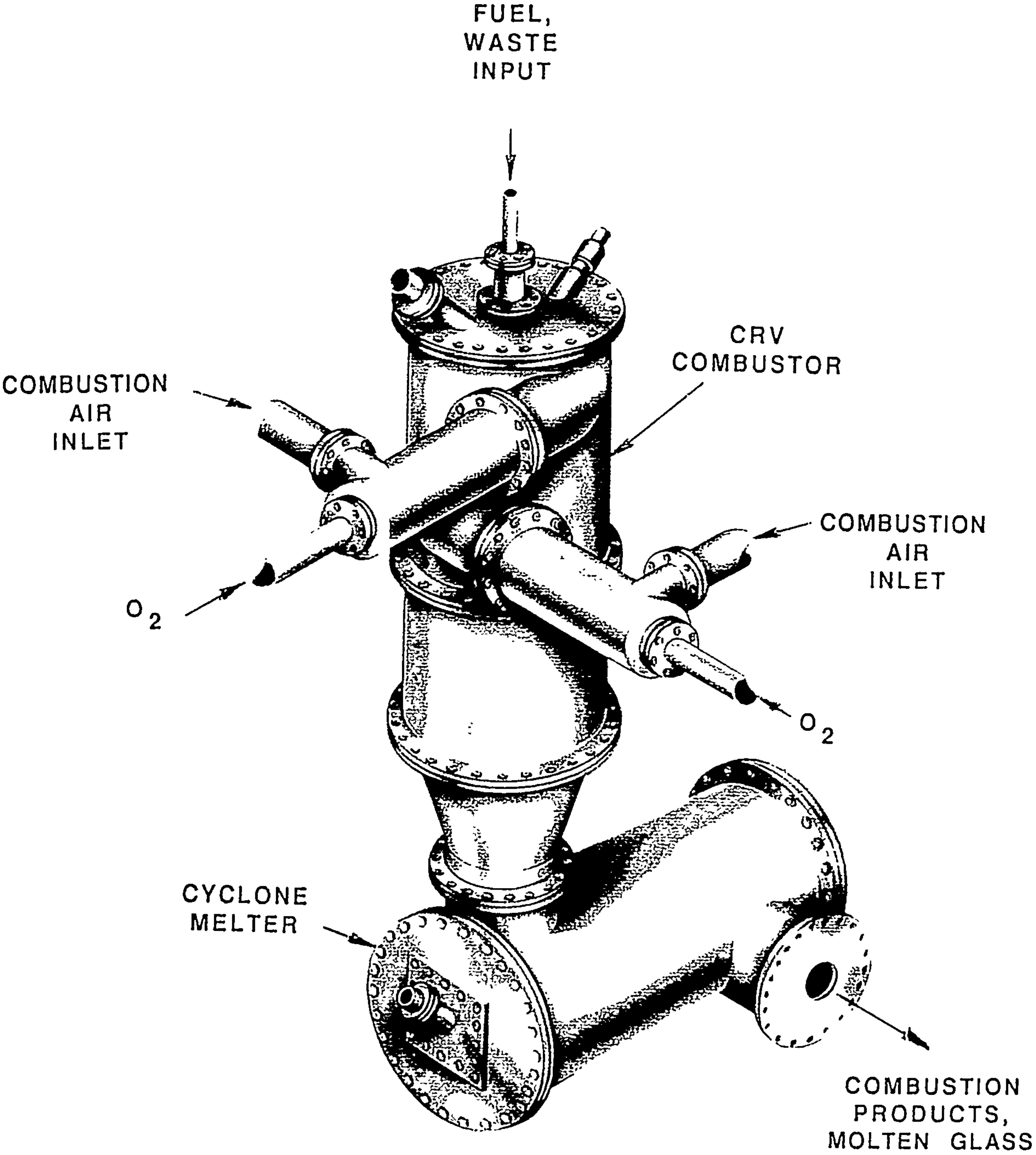


Figure 2.3-1. Artist Rendering of Basic CMS™

flow of glass basis, the 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, there are demonstrated reductions of SO_x emissions from the combustion of medium or high sulfur coals in the CMS™ 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, inorganics in the feedstock and ash from the coal, from the CRV combustor enter the cyclone melter where they are distributed to the chamber walls by cyclonic action to form a molten glass layer. Because of the high energy efficiency of the process, the ratio of coal ash to feedstock is small. The coal-to-feedstock input mass ratio is typically 0.2:1, therefore, the ash to feedstock ratio is typically 0.02:1 or less. The glass produced and the exhaust products exit the cyclone melter through a tangential exit channel.

A process diagram of a Vortec CMS™-based commercial ash vitrification and recycling system is shown in Figure 2.3-2. An artist rendering of a 200 tons/day commercial facility is shown in Figure 2.3-3. The basic elements of a commercial 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.

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

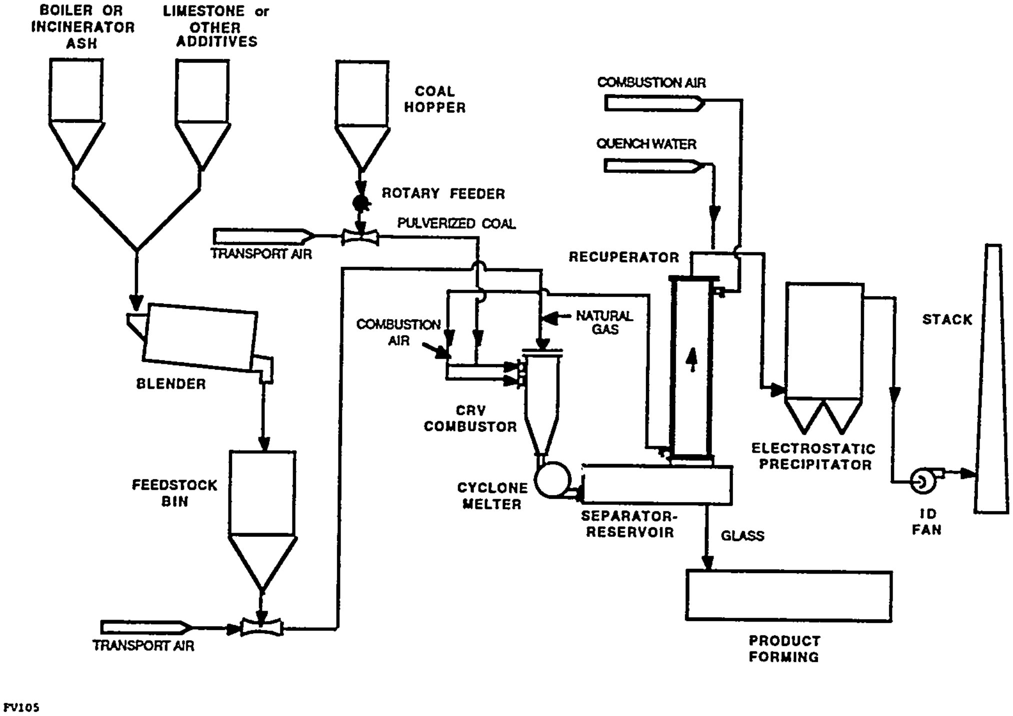


Figure 2.3-2. Vortec Ash Vitrification And Recycling System

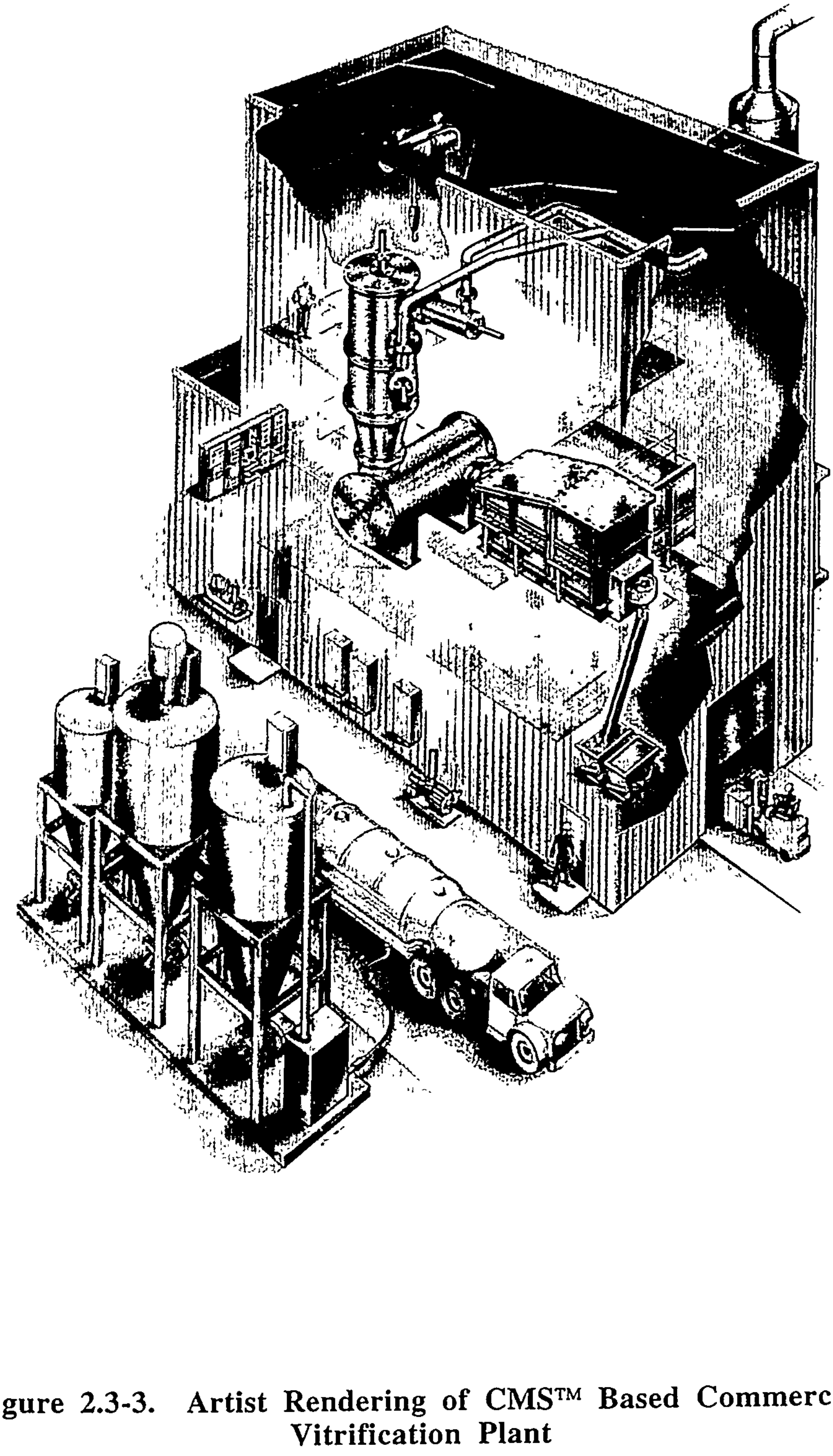


Figure 2.3-3. Artist Rendering of CMS™ Based Commercial Vitrification Plant

pulverized coal, coal slurry fuels, natural gas, and oil. The CMS™ can also be modified to accommodate oxygen enrichment of the combustion air or 100% oxy-fuel firing.

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™.

Vitrified product (glass) exiting the cyclone melter in the CMS™ enters a 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.

A 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. 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 can 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, depending on the material being vitrified.

A photograph of a 15 tons/day CMS™ installed in a test facility in Harmarville, PA, under this program is shown in Figure 2.3-4. The system and facility contain all the components of a commercial system producing glass frit except a recuperator which would be typical of that currently used in fiberglass manufacturing plants. Combustion air is preheated in the test facility via an indirect, natural gas fired heater.

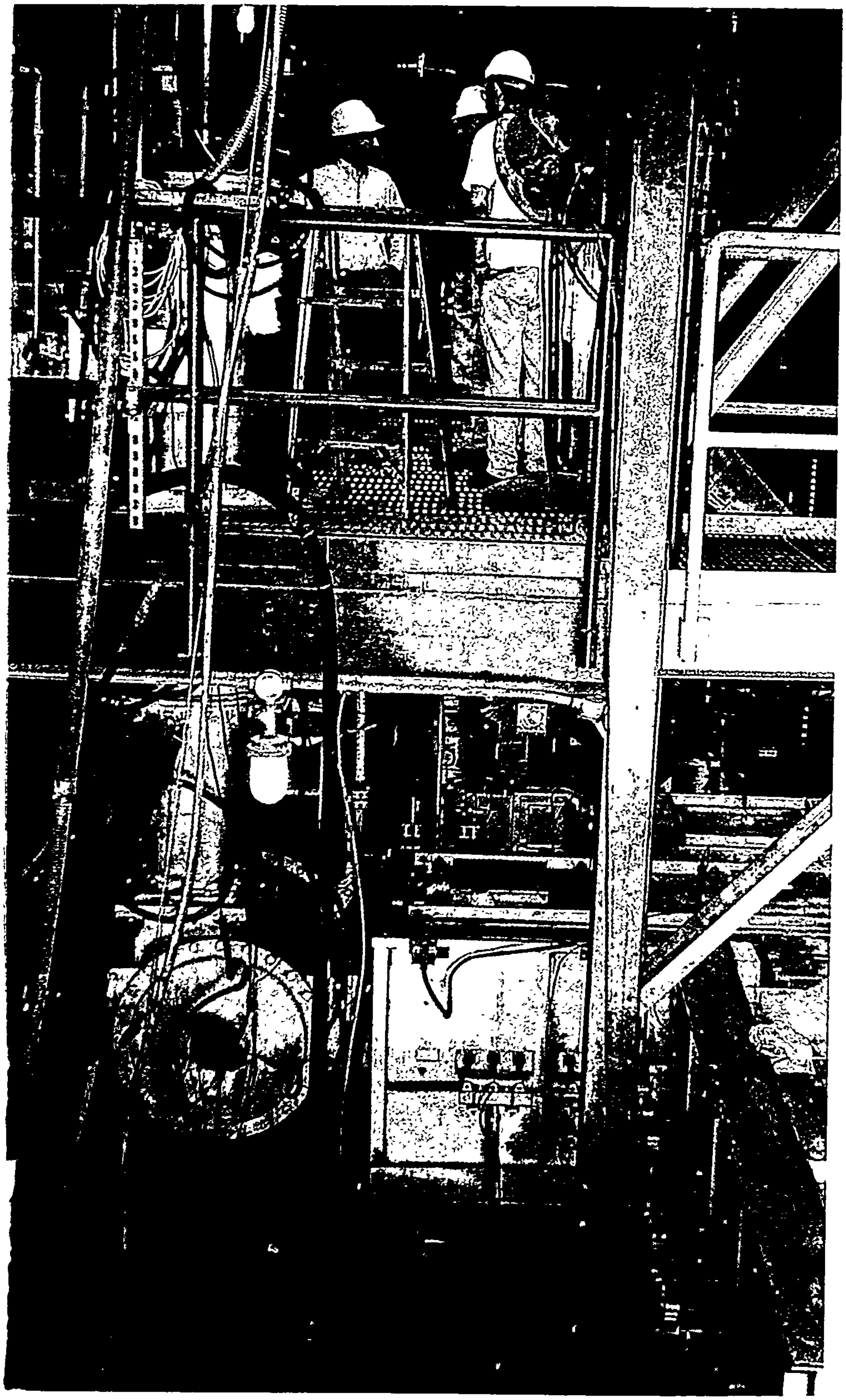


Figure 2.3-4 Photograph of 15 ton/day CMS™

3.0 PHASE III PROJECT DESCRIPTION

3.1 PROJECT OBJECTIVE

The primary objective of the Phase III project was to develop and integrate all the subscale CMS™ system components, from fuel through total system controls, and then test the complete system in order to evaluate its potential marketability.

3.2 PROJECT DESCRIPTION

Phase III was divided into seven (7) technical tasks and a program management task performed over 36 months. The Phase III work breakdown structure is provided in Table 3.2-1.

3.3 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. Procedures for protecting proprietary information have been implemented with our subcontractors and consultants via non-disclosure/patent agreements.

Table 3.2-1
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

4.0 PROJECT RESULTS

4.1 COMPONENT DESIGN, FABRICATION, AND INTEGRATION

Test operations for the Cyclone Melting System (CMS™) are located at Vortec's High Temperature Process Test (HTPT) Facility in Building B11 of the University of Pittsburgh Applied Research Center (U-PARC), shown in Figure 4.1-1. The HTPT facility is a high bay test area (40' W x 100' L x 60' H) and includes: natural gas, service and instrument air, electrical utility connections, a 5-ton overhead crane, and structural steel test towers with support/access platforms.

During Phase III, three similar test loops were utilized for process testing and optimization. Test Loop "3A" was the test loop from the end of Phase II, which consisted of coal fired precombustors, CRV combustor, cyclone melter, separator reservoir, and a wet venturi scrubber for particulate clean-up. Phase III testing showed that the wet venturi scrubber installed in Phase II was not adequate for collecting sub-micron particulate that was produced in the waste vitrification experiments. As a result, Test Loop "3B" was created to add a wet electrostatic precipitator (WESP) to the back end of the process for better particulate control. The WESP was added in parallel to the existing wet venturi scrubber; in this way the scrubber could act as a back up should there be problems with the WESP. Test Loop "3C" was created to support the Phase III extended duration demonstration test. For this test loop, the coal fired precombustors were removed from upstream of the CRV combustor because slag rejection was not a concern (a clear glass was not required), the L/D ratio of the CRV was increased to provide a longer residence time for better carbon conversion, a new coal feeding system was added outdoors to allow for loading of coal while the system was running, and the indoor coal system was converted to a batch tank to allow for continual batch feeding during the test.

An isometric diagram of Test Loop "3A" operated during Phase III is presented in Figure 4.1-2. As shown, batch is metered, conveyed pneumatically, and injected into the top of the CRV combustor. Natural gas is used for startup, and is fed through either the top of the CRV combustor by a dual-fuel injector, or directly into the coal fired precombustor. Coal is metered and fed simultaneously to axially oriented coal injectors in the precombustors. Firing the CRV combustor directly with coal, if desired, can be attained by minor piping modifications to the test loop. The batch materials introduced into the CRV

Figure 4.1-1
Bldg. B11 at U-PARC

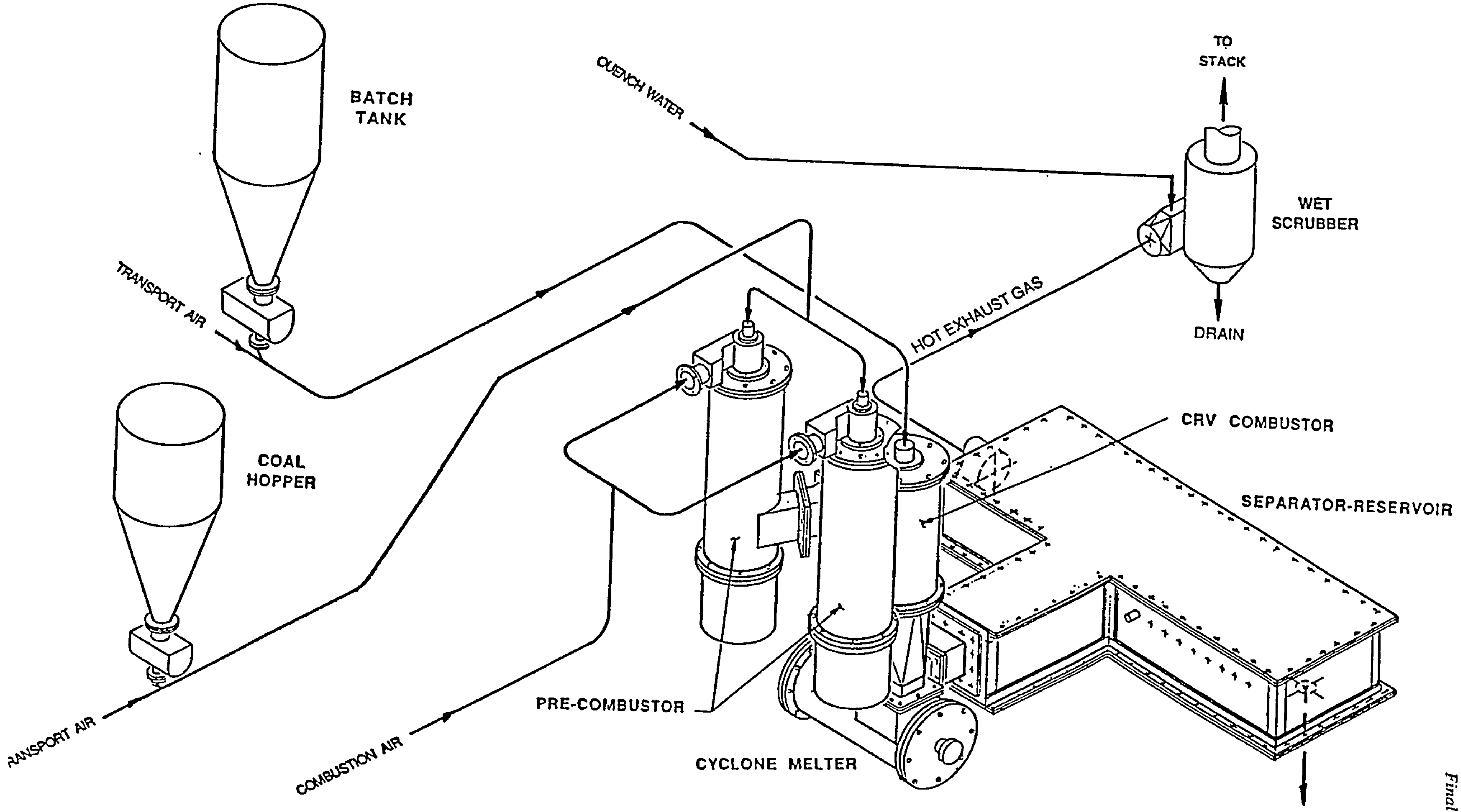


Figure 4.1-2
Test Loop "3A" Isometric Diagram

combustor are preheated, both in suspension and along the walls of the combustor, to glass melting temperatures prior to exiting the CRV combustor. The preheated batch materials exiting the CRV combustor enter the cyclone melter via a tangential inlet, and are separated to the walls of the cyclone melter via gas dynamically induced centrifugal forces. Primary glass forming reactions occur in the cyclone melter when the glass forming ingredients are brought into physical contact with each other.

Both the glass formed in the cyclone melter and the combustion products exit the melter co-currently through a tangential exit, and enter a separator reservoir where flue gases and the melted glass product are separated. Flue gases exit the separator reservoir through a side exhaust port and are quenched in a water spray to reduce the gas temperature. The flue gases then pass to a wet venturi scrubber prior to being released to atmosphere through a stack. The molten glass product is retained in a heated reservoir to provide time for fining the glass. Glass product is withdrawn through a tap hole located in the separator reservoir for sampling and disposal. A glass discharge tube and water-filled cullet cart provide for additional withdrawal of glass should the glass production rate exceed the tap-off capacity. A drain hole is provided in the separator/reservoir to allow draining the reservoir section at the end of a test run.

The Vortec HTPT Facility Layout for Test Loop "3A" is shown in Figures 4.1-3 and 4.1-4. A photograph of the test loop is shown in Figure 4.1-5. As shown in Figures 4.1-3 and 4.1-4, the combustion air blower, the process air heater, and the dust collector for venting the coal and batch tanks are located outdoors on the north side of Building B11. The major process components are located between column lines 3 and 4, above level 2 elevation (880'-10"). Process feedstocks are delivered to the site at either the north loading dock or the west high-bay door, and then transferred to a storage area within the high bay area using a 5-ton overhead crane. A materials processing facility is located along the South wall between column lines 1 and 3 to prepare batch materials with specified size distributions. The coal tank and batch tank are supported at the level 5 (914'-10") elevation. The central control room is located in the southeast corner of the facility between column lines 5 and 8, at the level 2 elevation (880'-10").

As mentioned previously, Test Loop “3B” was created by adding a WESP in parallel with the wet venturi scrubber. With the exception of the added WESP, flow diagrams for both test loops are the same.

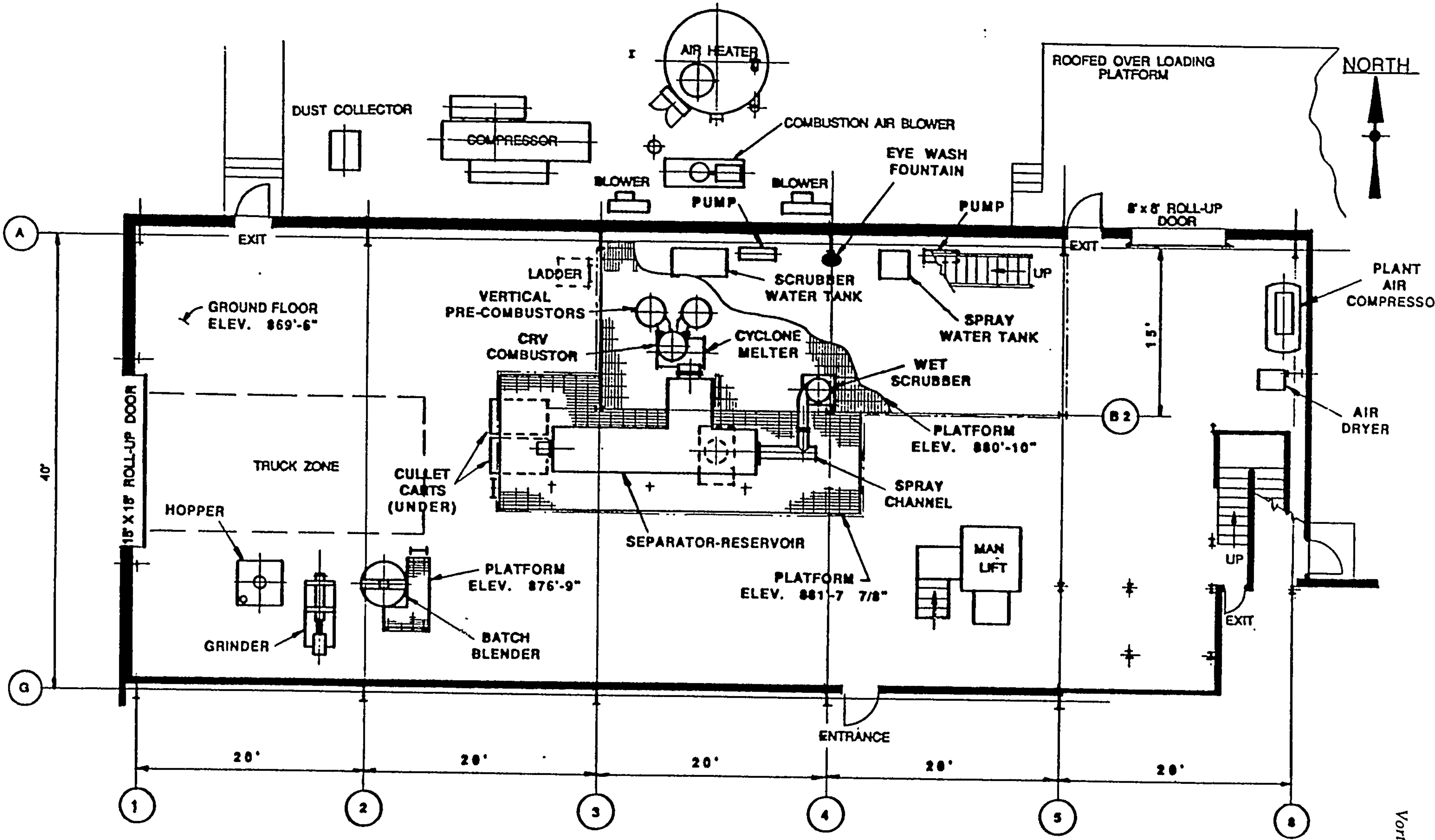


Figure 4.1-3
Test Loop "3A" Plan - Elev. 869'-6"

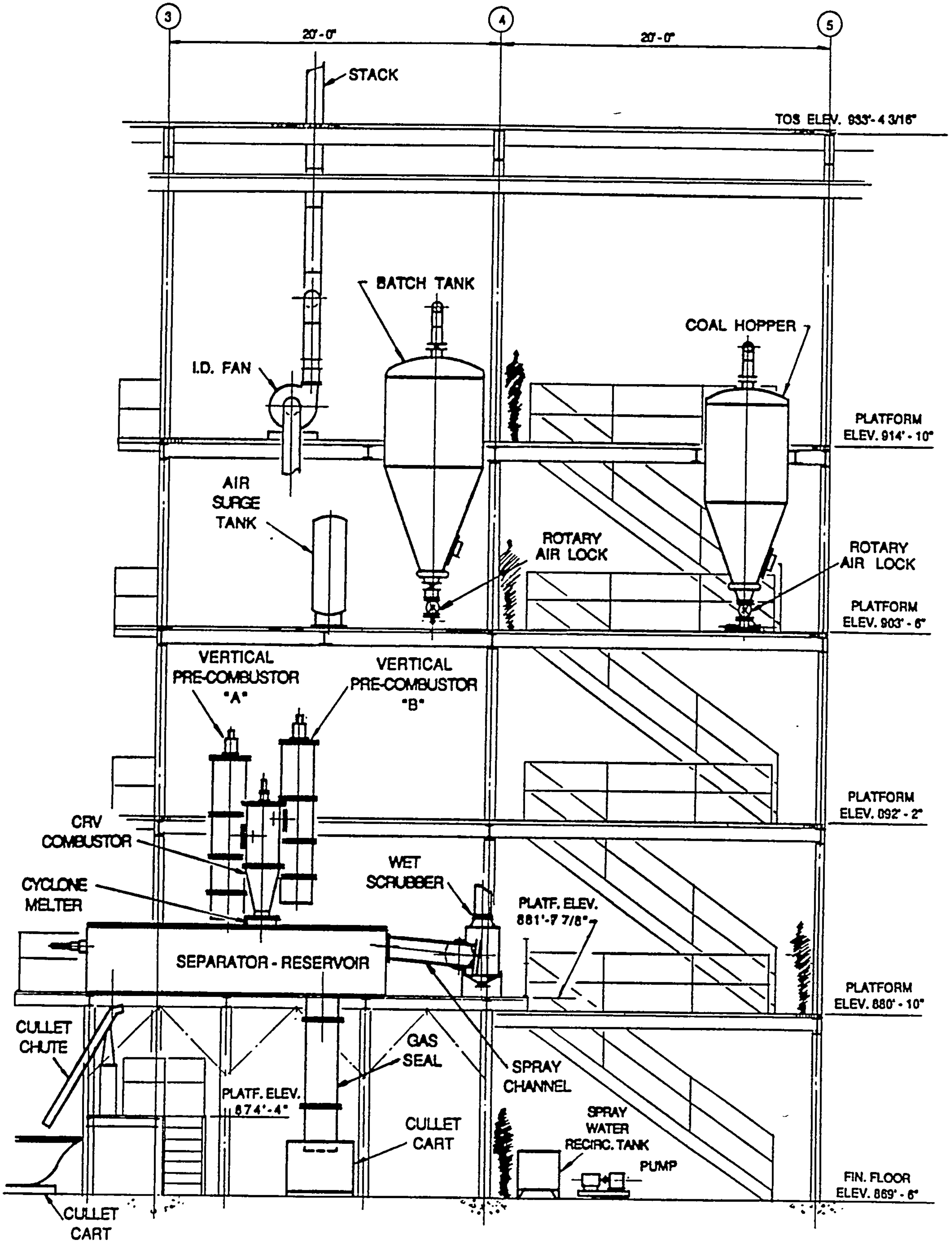


Figure 4.1-4
Test Loop "3A" Elevation Looking North

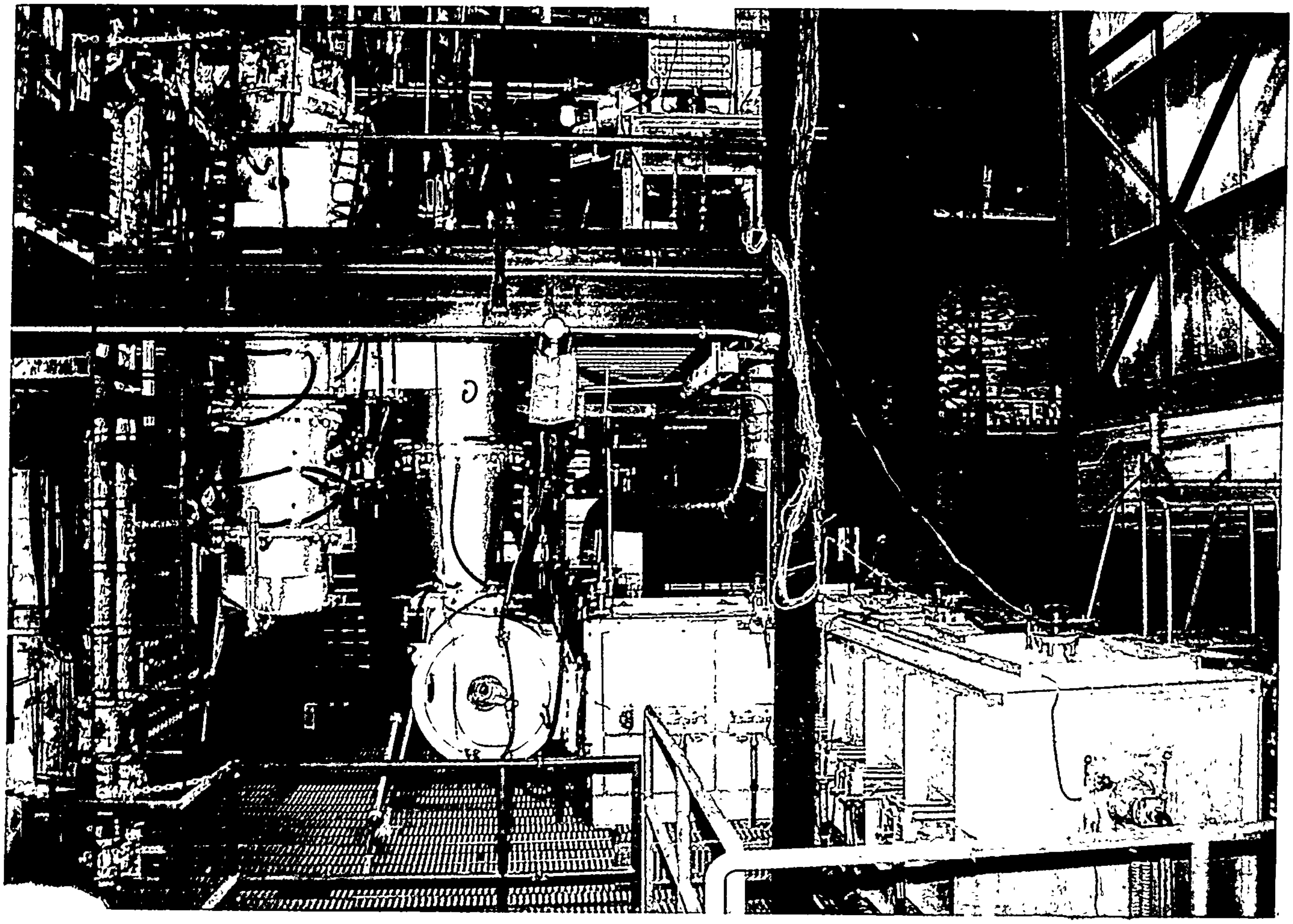


Figure 4.1-5
Photograph of Test Loop "3A"

An isometric diagram of Test Loop "3C" is presented in Figure 4.1-6. As shown, the vertical precombustors have been removed and now both pulverized coal and batch are injected axially into the CRV combustor by a special dual feed injector. For natural gas operation the gas is injected into the CRV combustor inlet arms. Two batch tanks are provided so the system can operate from one tank while the other tank is being filled. A new coal feed system which can be loaded with coal while maintaining feed to the CRV combustor has been added. Also shown is the WESP in parallel with the wet venturi scrubber. Dampers within the duct work allow the operator to choose which back end cleanup system will be utilized for a particular test setup.

The Vortec HTPT Facility Layout for Test Loop "3C" is shown in Figures 4.1-7. As shown, the main process equipment is still located between column lines 3 and 4. The WESP is located outside, just North of the building, between column lines 4 and 5. The new coal feed system is also located outside between column lines 2 and 3. The coal system was located outdoors for safety reasons. Having the coal system outside prevents the ignition of coal dust from possible spills during loading operations.

The following sections provide a summary description of the major components/systems which comprise the Vortec CMS™ Test Loop.

4.1.1 Process Air Supply and Preheat System

Preheated air is supplied to the process by a Thermoflux indirect-fired air heater, shown in Figure 4.1-8, located outdoors and to the North of Building B11. The burner controls, control panels, and safety related equipment are all integral to the unit and are independent of the main process controls. Controls to stop/start the system are manually operated. The heater can be brought into service quickly since it contains no refractory. The air heater outlet temperature is controlled directly by firing rate. A controller which monitors outlet temperature limits the firing rate to prevent exceeding the safe operating temperature limits of the air heater's tube material.

Air to the Thermoflux heater is supplied by a Lamson Series 558-AD Turbo Air blower. Power is supplied by a 60 HP, 3600 RPM, 460V TEFC motor, and flow control is provided by a 6 inch butterfly valve. To prevent surge during start-up, a two-inch lever-operated valve vents to atmosphere through a silencer.

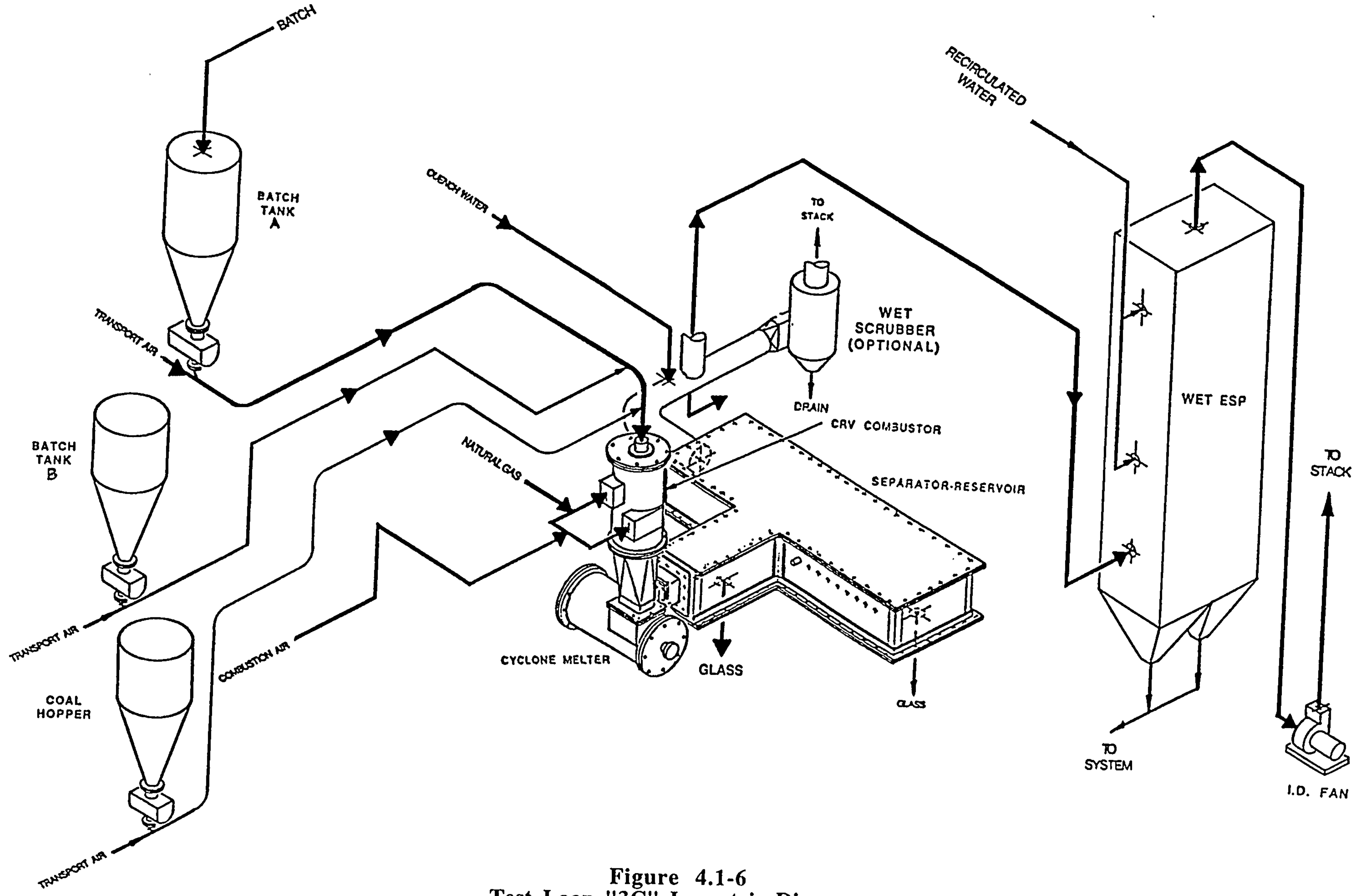


Figure 4.1-6
Test Loop "3C" Isometric Diagram

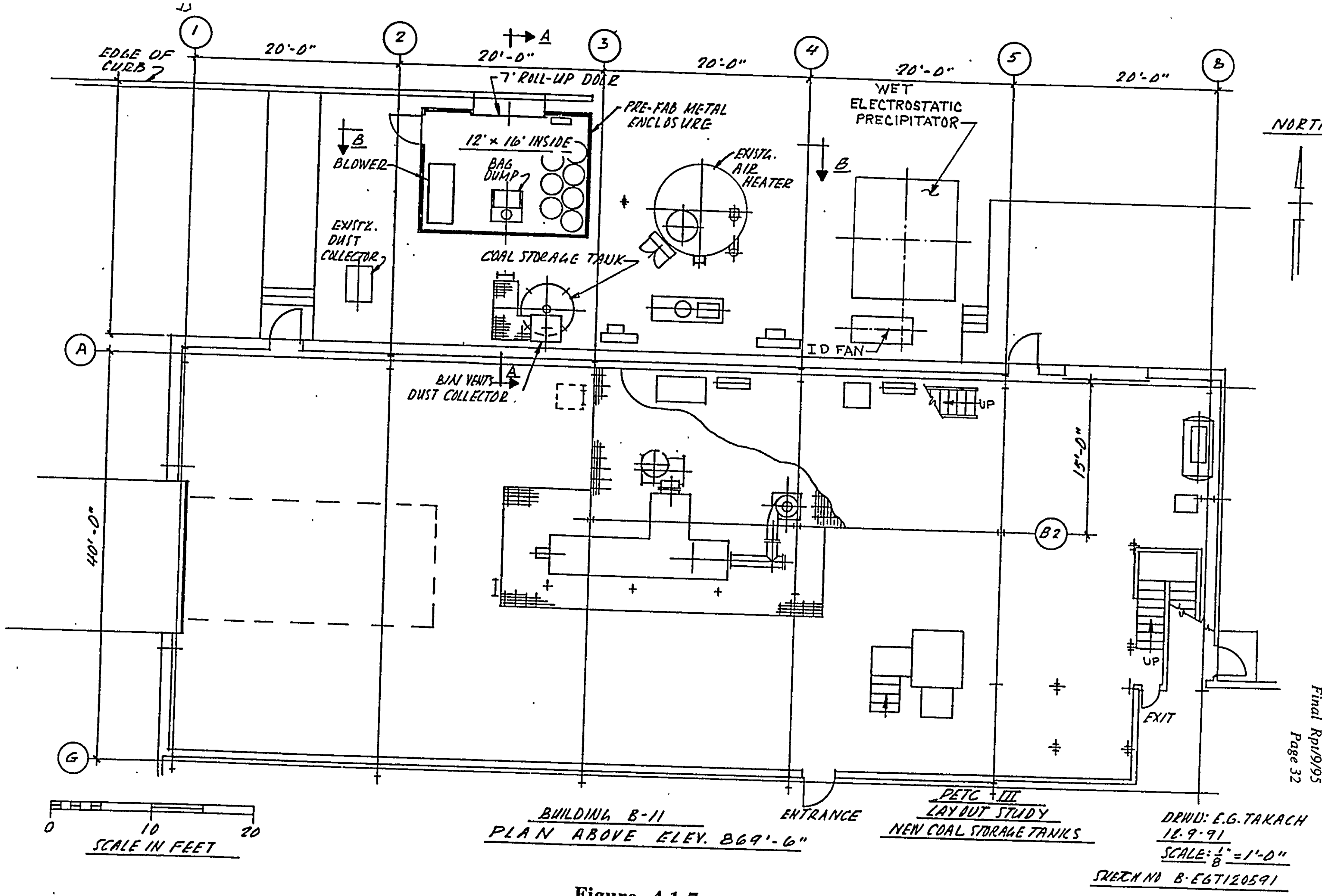


Figure 4.1-7
Test Loop "3C" Plan - Elev. 869'-6"

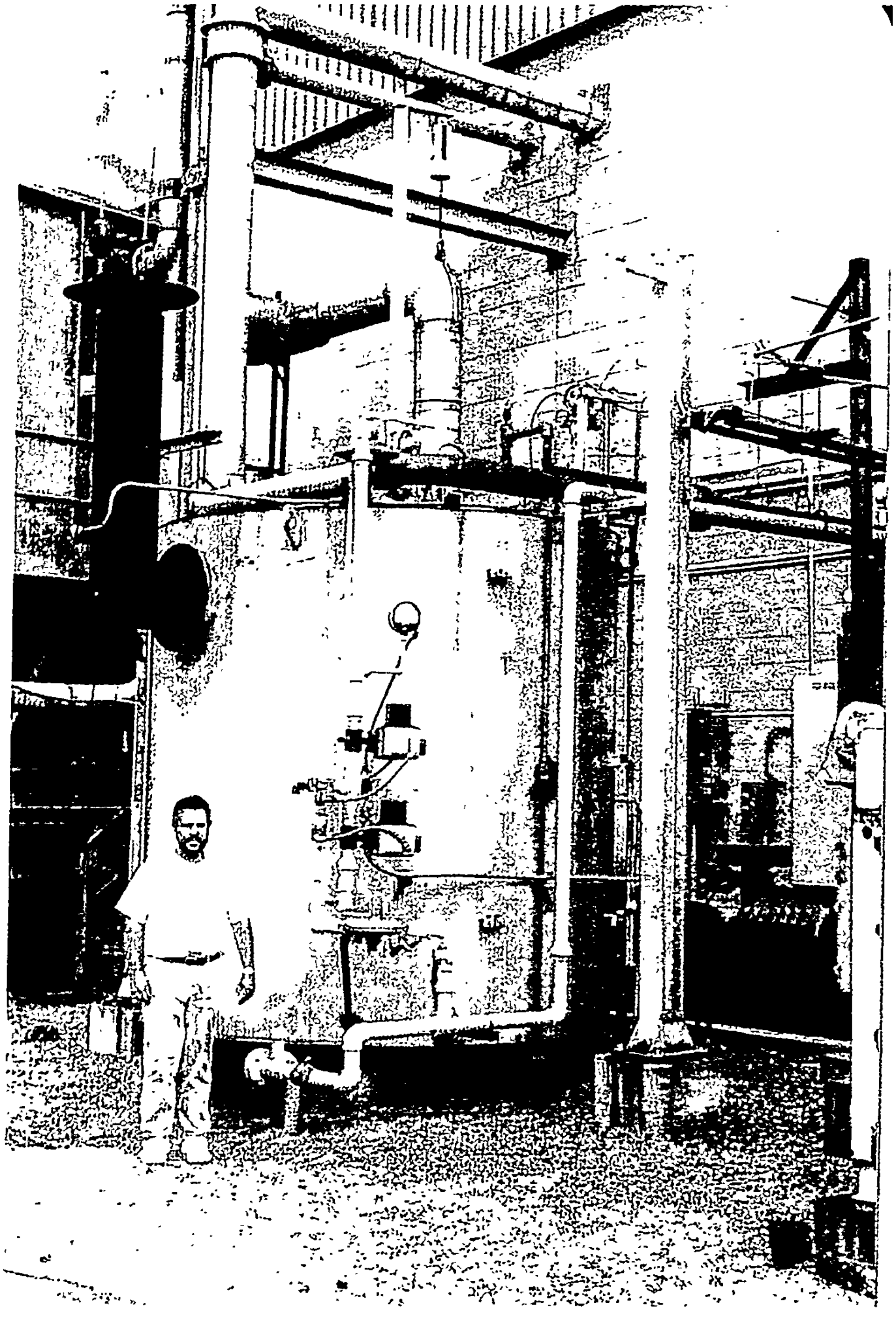


Figure 4.1-8
Indirect Fired Air Heater In
Pilot Scale Test System

Flow through the Lamson blower is monitored with an orifice plate. A computer generated interlock prevents the air heater from starting below a certain minimum airflow. The natural gas safety controls for the air heater consist of a double block and vent valve. The burner management system was supplied by North American Manufacturing Co. The heater will trip on high/low gas pressure, low combustion air pressure, high outlet temperature, and loss of flame. Start-up of the Thermoflux heater is initiated by a single push button located in the control room. Start-up is controlled by the burner management system which provides the necessary purge and flame detection for both the interrupted pilot and main burner.

4.1.2 Coal Supply/Feed System

During Phase III, two different coal feed systems were utilized. The original coal feed system installed during Phase II was used in Test Loops 3A and 3B, while a new system was installed for Test Loop 3C. For both systems, however, coal was delivered to the site in 55 gallon drums and inventoried in either of two material storage areas. Both systems were designed to handle either as received, washed or deep-cleaned pulverized coal. The following discussions describe the two coal feed systems utilized during Phase III.

Coal Supply/Feed System for Test Loops 3A and 3B

In the coal supply/feed system for Test Loops 3A and 3B, pulverized coal is metered and delivered to the process via a pneumatic conveying system depicted in Figure 4.1-9. A photograph of the coal storage tank with feeder is shown in Figure 4.1-10.

When preparing for a test run, coal is hoisted from the temporary storage area to level 5, adjacent to the coal hopper area, by the overhead crane. For safety, once all the coal is on Level 5, the overhead crane and other electrical equipment in the area is "locked out" during coal loading operations by opening their disconnect switches. The coal is transferred from the 55 gallon drums into the storage hopper with a manual unloader which allows for balanced tipping/pouring of the pulverized coal into the hopper. A special spout and funnel are designed to minimize spillage. A fugitive dust control system continuously draws air through the top of the coal hopper, creating a negative pressure at the spout/hopper interface. Dusty air is drawn through a "Dustkop" Model FT24S21-D fabric filter located outside building B11.

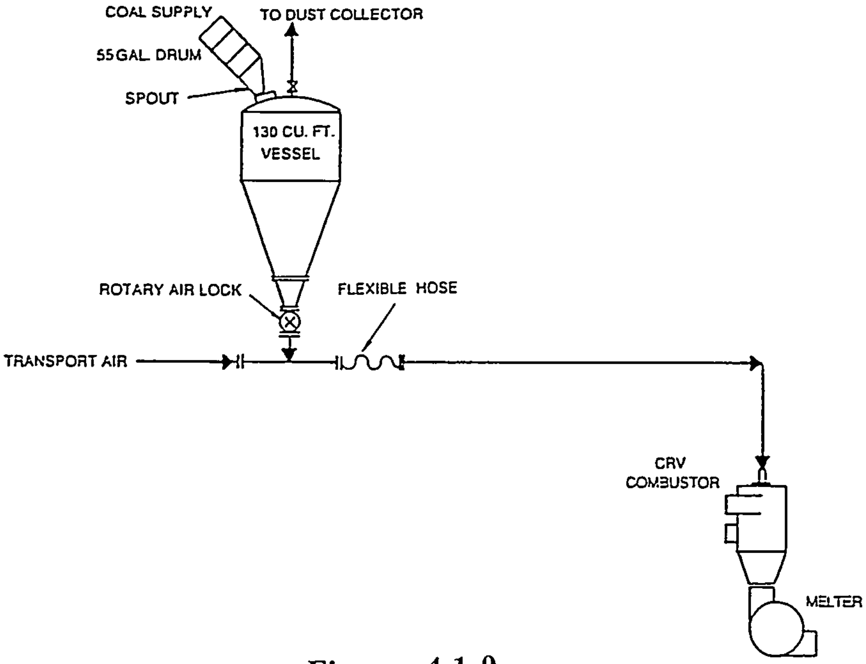


Figure 4.1-9
Coal Feed System Schematic
Test Loops 3A and 3B

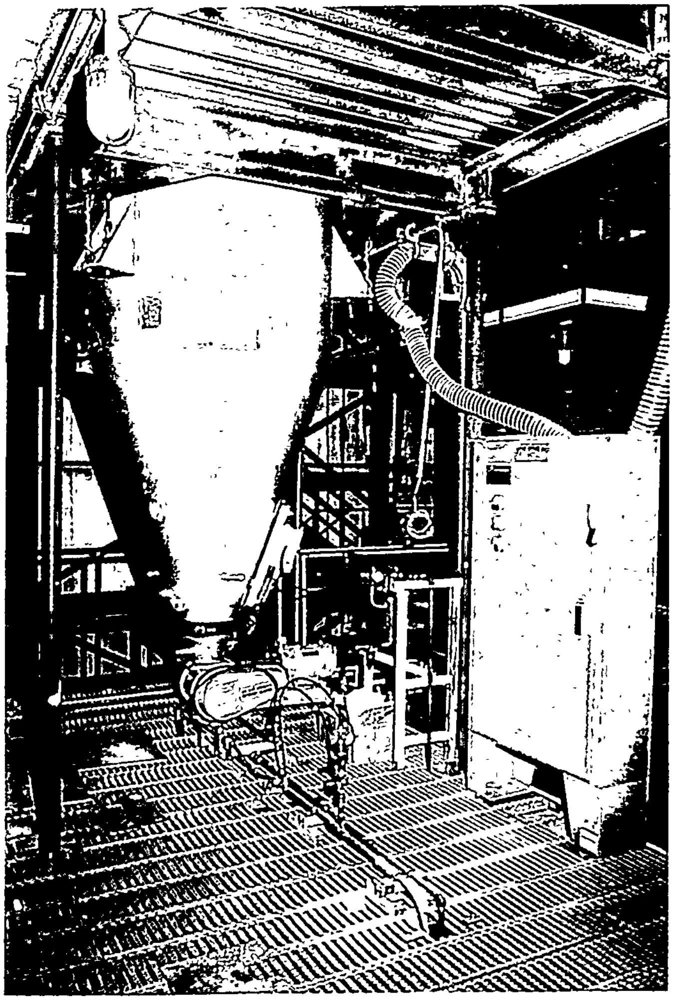


Figure 4.1-10
Coal Feed System in Pilot Scale Test System
Test Loops 3A and 3B

The coal storage tank has a nitrogen blanketing system to safely store coal prior to a test. This system consists of four standard nitrogen filled bottles (230 cu. ft.), one main regulator to reduce bottle pressure to 80 psig, and one secondary regulator to reduce from 80 psig to 10 ounces maximum discharge pressure. Once the coal is loaded in the hopper, the hopper is sealed, the secondary regulator by-passed, and the line opened to fill the hopper with nitrogen. When the hopper is filled with nitrogen, the secondary regulator is activated and the hopper held at 10 ounces until the feed system is operated.

The storage tank has a 130 cu. ft. capacity and is supported on weigh cells to determine feed rate during operation. During operation, the nitrogen blanket above the coal is maintained. A calibrated staggered vane pocket feeder (16 vanes, 32 pockets) meters coal to the process within a range of 185 to 400 lbs/hr. Flow rate is controlled by varying the speed of the pocket feeder. The coal is pneumatically transported to the precombustors or CRV combustor via a 1/2 inch schedule 40 line with an 11:1 solids-to-air ratio. Air assist taps are provided in the feed line to keep the material free-flowing, if this becomes necessary.

Air for pneumatic transport of coal to the coal combustion assembly is supplied by 100 psig service air. Instrument air requirement is 5 SCFM and transport is 10 SCFM (average).

Air assists are also provided at regular intervals on the transport line to promote the flow of coal.

An alarm message warns the operator in the event the feed rate falls outside an acceptable range. In the event of a flame out, the coal transport system automatically shuts off.

Coal Supply/Feed System for Test Loop 3C

From a safety standpoint, the coal system described above did not lend itself to reloading the coal tank during continuous operation of the CMS™. Possible spills from the filling operation would expose coal dust to potential hot exhaust gases, open flames in the facility, and sparks from electrical equipment. Therefore, it was necessary to install a new coal handling system outdoors. A schematic of the coal feed system used in Test Loop 3C is shown in Figure 4.1-11.

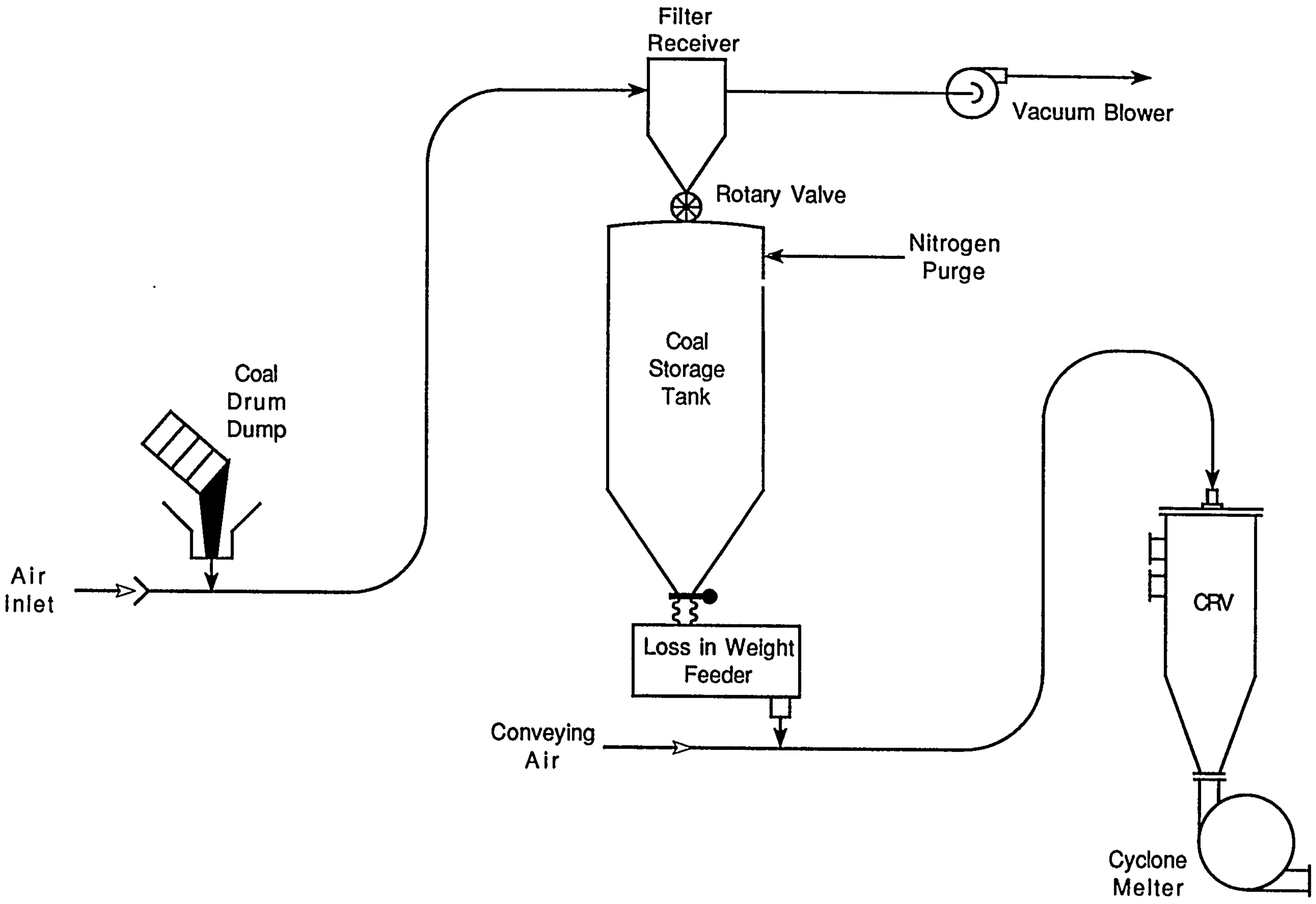


Figure 4.1-11
Coal Feed System Schematic
for Test Loop "3C"

When preparing for a test run, drums of coal are brought by a fork lift from the storage area to a concrete pad adjacent to the coal drum dump hopper. The coal is transferred from the 55 gallon drums into the drum dump hopper with a manual unloader which allows for balanced tipping/pouring of the pulverized coal into the hopper. A vacuum blower draws air through the conveying line under the drum dump hopper. Coal falls from the drum dump hopper into the conveying line where it becomes entrained in the conveying air. The coal is then transported to a filter receiver located above the coal tank. Filter bags in the filter receiver separate the coal from the air, the coal falls into a hopper while the air passes through a secondary filter prior to the vacuum blower. The secondary filter protects the vacuum blower in the event of a filter bag leak. Pulverized coal passes from the filter receiver hopper to the coal storage tank through a 16 vane rotary feeder. The coal storage tank has a nitrogen blanketing system to safely store the coal during operation. Nitrogen for this system is supplied in a liquid nitrogen dewar fitted with a regulator to supply nitrogen at about 20 psig, secondary regulators maintain the coal tank at 10 to 20 in. wg.

Coal in the 200 cu. ft. capacity storage tank passes to a loss in weight feeder through a pneumatically operated butterfly valve. The loss in weight feeder has a small hopper which holds about 250 pounds of pulverized coal. A small screw conveyor transports coal from the hopper and discharges it into an eductor located in the coal feed line to the CRV. The screw conveyor and the small coal hopper are mounted on load cells which monitors the total weight of the assembly. The coal handling system's PLC performs a loss in weight calculation, compares the calculated feed rate to the setpoint, and adjusts the speed of the screw conveyor as required. When the assembly weight reaches a low set point, the butterfly valve in the coal tank opens to refill the small coal hopper on the loss in weight feeder. When the hopper is filling, the screw conveyor maintains a constant speed until the PLC is able to resume the loss in weight calculation.

The coal is pneumatically transported to the CRV combustor through a 1-1/2 inch schedule 40 line with a 3:1 solids-to-air ratio. Transport air is supplied by 100 psig service air. Instrument air requirement is 5 SCFM and transport is 20 SCFM (average).

An alarm message warns the operator in the event the feed rate falls outside an acceptable range. In the event of a flame out, the coal transport system automatically shuts off.

4.1.3 Batch Supply/Feed System

During Phase III, two different batch feed systems were utilized. The original batch feed system installed during Phase II was used in Test Loops 3A and 3B, while for Test Loop 3C the original coal feeding system was converted into a batch handling system, thereby providing two batch tanks. For both systems batch is delivered to the site in 1000 lb "Supersacks" and stored in either of two material storage areas. The following discussions describe the two batch feed systems utilized during Phase III.

Batch Supply/Feed System for Test Loops 3A and 3B

In preparation for a test, "Supersacks" are hoisted up to the batch tank by an overhead crane, which is provided with a special carrying fixture to support the "Supersack" while its contents are emptied into the batch tank at level 5 elevation (914'-10"). Batch material is loaded through an 18 inch diameter manway in the vessel head, shown in Figure 4.1-12. A fugitive dust control system continuously draws air through the top of the batch tank, creating a negative pressure at the "Supersack"/hopper interface. Dusty air is drawn through a "Dustkop" Model FT24S21-D fabric filter located outside the building, exhausting clean air to the environment.

The batch is blended, metered, and delivered to the process via the NOL-TEC Systems conveying system, a schematic of which is shown in Figure 4.1-13.

The storage tank has a capacity of 150 cu. ft. and is supported on weigh cells to determine feed rate during operation. A calibrated rotary feeder (12 pockets) meters batch to the process. During operation, the tank is pressurized and flow rate is controlled by varying the speed of the rotary feeder, and tank weight is measured through a system of three tension load cells. The batch is pneumatically transported to the CRV combustor with a 60:1 solids-to-air ratio. A photograph of the batch storage tank with blend and feed system is shown in Figure 4.1-14.

A view glass is provided in the transport line downstream of the rotary feeder to observe pneumatic transport phenomena. A series of alarms are provided to warn of system malfunctions. In the event of a flame out, the batch transport system automatically shuts off.

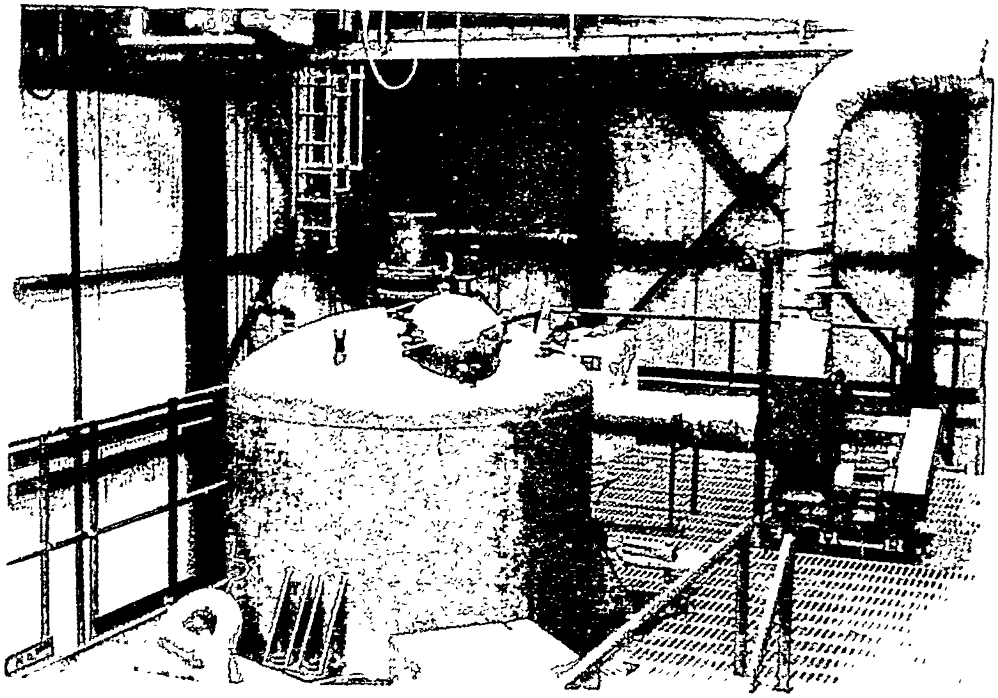


Figure 4.1-12
Photograph of Batch Storage Tank in
Pilot Scale Test System

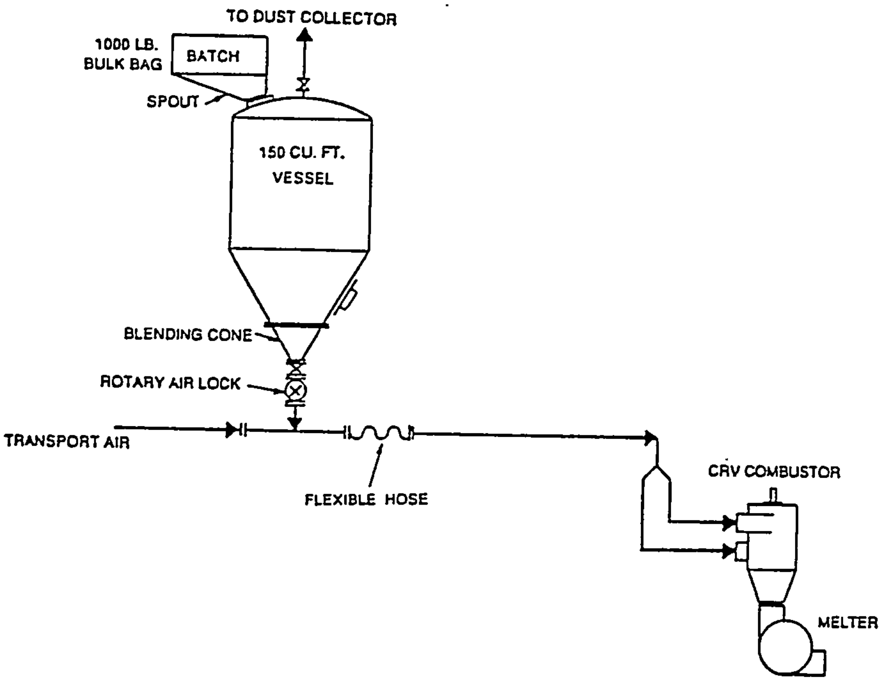


Figure 4.1-13
Batch Feed System Schematic

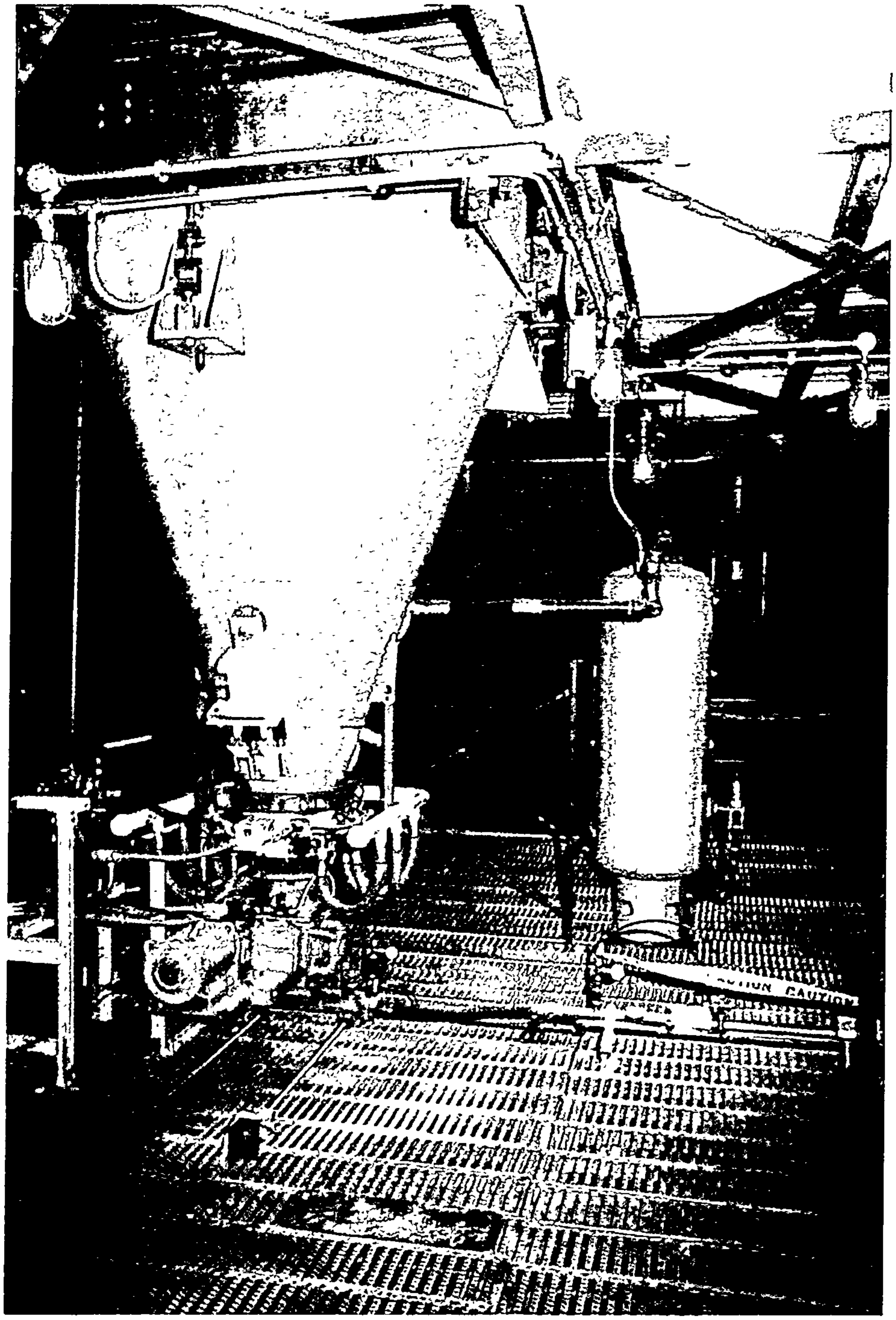


Figure 4.1-14
Photograph of Batch Feed System in
Pilot Scale Test System

Commercially available pneumatic blending capability is provided in the lower cone portion of the batch tank for mixing glass batch. Six solenoid operated air injectors, controlled by a programmable logic controller, are installed 60° apart on the lower cone to inject 30 psig air into the batch tank in a controlled sequence of pulses. As the air rises through the batch medium, it causes agitation and mixing of the batch products. Batch with a uniform particle size will be completely blended in a four minute blend cycle. When the particle size is not uniform, over blending can cause desegregation of the ingredients; therefore, trial blend cycles of varying duration must be made with samples taken after each cycle in order to determine the optimum blend time. A tracer dye, such as methylene blue, can be utilized to help determine the point when mixing is complete, as indicated by a uniform color of the mixed batch.

Batch will be blended following the fill of the storage tank. A bridge breaker system with adjustable on-off times is provided to keep the batch flowing. A series of alarms are provided to warn of system malfunctions in the blending system.

Batch Supply/Feed System for Test Loop 3C

For the extended duration demonstration test (100 hour test), it was necessary to run batch continuously. With only one batch tank continuous batch operation was not possible since reloading the batch tank typically takes 3 to 4 hours. A new coal system was installed for the 100 hour test, and the original coal tank was modified to provide an additional batch tank (Batch Tank "B"). With two batch tanks, one tank could be loaded while the other tank was operating.

The only modifications made to the existing coal handling system was to replace the rotary feeder with a 12 pocket feeder to match the existing batch feeder and to replace the 1/2 inch conveying line with a 1-1/2" schedule 40 line. A flexible connector was added to the batch feed line so either batch tank could be manually selected. Since manual change over from one tank to the other only takes two to three minutes, a pneumatic diverting valve was not felt to be necessary for the test.

In order to conserve money, a blend cone was not installed as part of the coal tank modifications. As a result, any batch fed by batch tank "B" was premixed, blended, and stored in supersacks until the test. Because tank "B" is smaller than "A", only about 30% to 40% of the total batch needed to be preblended.

4.1.4 Cyclone Melting System (CMS™)

The Vortec CMS™ consists of three subsystems, namely a set of coal-fired precombustors, the CRV combustor, and the cyclone melter. These items are discussed in the following sections:

4.1.4.1 Coal Fired Precombustor

The primary function of the coal fired precombustor assembly is to provide a combustion zone external to the CRV combustor to ensure complete carbon conversion of pulverized coal prior to the introduction of glass batch material. Typically two precombustors are utilized; one per CRV inlet arm.

An outline drawing of a vertical precombustor used in Test Loops "3A" and "3B" is shown in Figure 4.1-15. A photograph of the vertical precombustor is shown in Figure 4.1-16. Each precombustor has a nominal 1.5 to 2.0 x 10^6 Btu/hr thermal capacity at 20% excess air with coal combustion. Preheated air enters through an adjustable inlet located in the swirl box at the top of the precombustor. Coal is introduced axially through the top of the precombustor via a water cooled coal injector, and is combusted to provide heat for melting the batch materials. Turbulent action in the precombustor, adjustable by varying the position of the inlet valve, provides for excellent mixing and flame stabilization. This precombustor is a refractory lined, water jacketed, cylindrical vessel. Water cooling maintains the metal skin temperatures to less than 200°F. The temperature inside the precombustor is continuously monitored by a thermocouple to prevent damaging the refractory.

The precombustor assembly includes a gas fired pilot burner with its attendant flame safety system. The precombustor also has a natural gas injection port which allows for gas firing the unit to preheat refractory prior to firing on coal.

The precombustor is also provided with a slag tap, a slag tap burner system, and a slag pot. Depending upon the operating mode, this precombustor can be operated in either a dry ash or a slagging mode. Two 2 inch blast-gate observation ports are provided to allow for observation of the slag flow out of the precombustor.

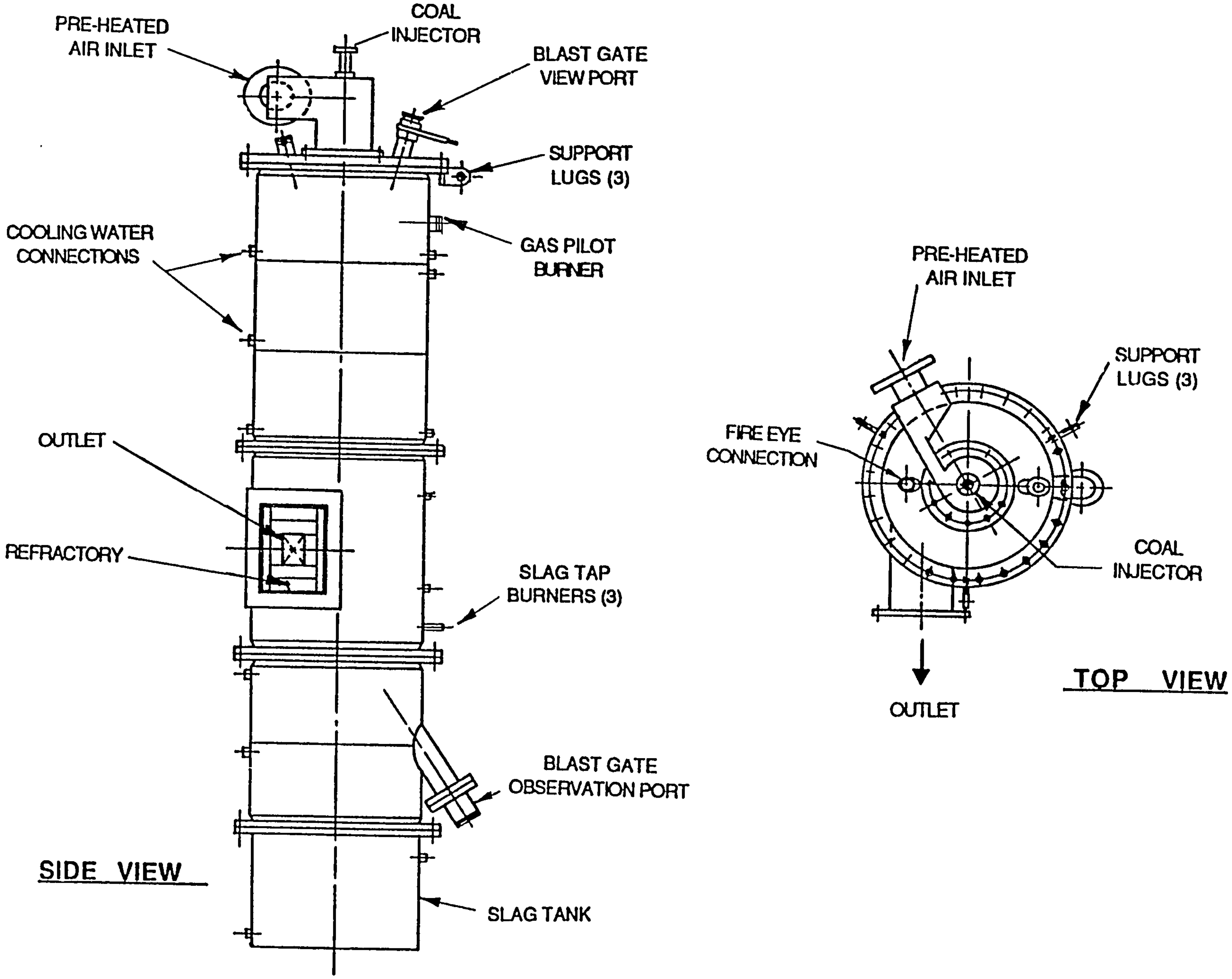


Figure 4.1-15
Vertical Coal-Fired Precombustor Outline

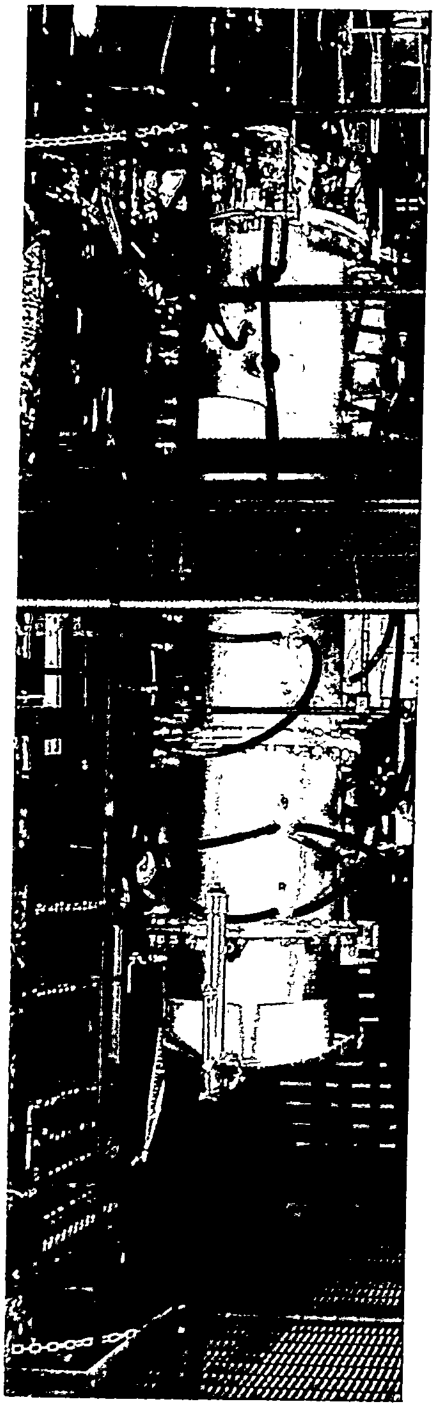


Figure 4.1-16
Photograph - Vertical Coal Fired Precombustor

The natural gas safety controls for the main gas consist of a double block and vent valve arrangement. Flame safety is provided by a Honeywell R4075 flame safeguard controller and a Honeywell C7106 UV detector with self-checking circuitry. The natural gas to both precombustors will automatically trip on high/low gas pressure, loss of combustion air, loss of flame in either precombustor, and loss of cooling water.

Coal flow to the precombustors is controlled by the rotary feeder in the coal handling system. The rotary feeder is interlocked with the flame management system for the precombustors so that the coal feed will automatically trip on loss of combustion air, loss of flame in either precombustor, and loss of cooling water.

A 200,000 Btu/hr commercial pilot burner supplied by Bloom Engineering is natural gas fired, and is located on the side of the precombustor. It is used to ignite either the coal or gas flame. It is manually started, but regulation is automatic, along with associated interlocks and alarms. A UV-type flame detector located within the pilot assembly provides verification of a stable flame, and provides supervisory/interlock to disable fuel supply in the event of a flameout. The flame safety system utilizes a Honeywell C7027 UV mini-peeper along with a Honeywell RA89 primary safety controller. Permissive circuitry allows opening of the main fuel valve or start-up of coal feed only when the pilot is "on".

The slag tap burner system consists of three 20,000 Btu/hr commercial pilot burners supplied by Bloom Engineering. The burners are natural gas fired and are located on the side of the precombustor below the slag tap opening. The burners are operated to keep the slag tap refractory hot, thereby preventing slag from freezing in the slag tap. The slag tap burners have no flame safety controls, instead they are turned on manually during heat up when the precombustor temperature is over 1400°F. At this temperature the premix burners will auto-ignite. The gas supply for the slag tap burners is taken after the main gas valve, so the burners cannot be turned on unless the main flame is lit. Should the main flame fail, the slag tap burners will be shut off when the gas valve closes.

Vortec's research efforts have shown that the best near term application for a coal fired CMS™ is in the vitrification of fly ash for the manufacture of value added glass products. In this application, the ash from the coal combustion would become part of the feedstock for the product being produced. As a result, it was decided to remove the precombustors for the 100 hour test, whose purpose was to demonstrate the potential for this application, since slag rejection would not be required and a better overall heat rate for the system could be obtained. The precombustors were available in test loops "3A" and "3B", but not in "3C".

4.1.4.2 Counter Rotating Vortex (CRV) Combustor

The primary function of the CRV combustor is to raise the temperature of the batch ingredients above the melting temperature, typically 2200°F for insulation fiberglass to 2900°F for high melting point ashes, by suspension heating with combustion gas temperatures ranging from 3300° to 4000°F. The CRV combustor is designed for a nominal 3 to 5 x 10^6 Btu/hr thermal input with 5 to 20% excess air. An outline drawing of the CRV combustor is shown in Figure 4.1-17. A photograph of the pilot-scale CRV combustor is shown in Figure 4.1-18.

The CRV combustor can either be direct fired or externally fired in Test Loops "3A" and "3B", and direct fired only in Test Loop "3C". Under direct firing, preheated air passes through the precombustors (in Test Loops "3A" and "3B" only) and enters the CRV combustor through counter-rotating tangential inlet slots located at the side of the combustor. Coal and/or natural gas are introduced axially through the top of the CRV combustor via a dual fuel injector. Fuel is combusted within the CRV combustor, providing heat for melting the batch, which is also injected axially. Turbulent action, made adjustable by varying the flows between tangential inlet slots, provides for excellent mixing and combustion in the CRV combustor. Where coal ash contamination is a concern, the CRV combustor can be externally fired with the coal fired precombustors. In this mode, the precombustors are operated in a slagging mode to reduce coal ash loading of the process. The hot combustion gases enter through the tangential inlet slots while the batch is injected axially. Again, strong turbulent mixing action occurs within the CRV combustor to preheat the batch materials to proper melting temperatures.

The CRV combustor is a vertically oriented, refractory lined, water jacketed cylindrical vessel. Water cooling is provided within a narrow passage at the vessel wall to maintain metal skin temperatures to less than 200°F. Temperatures of the refractory at the CRV combustor exit are continuously monitored.

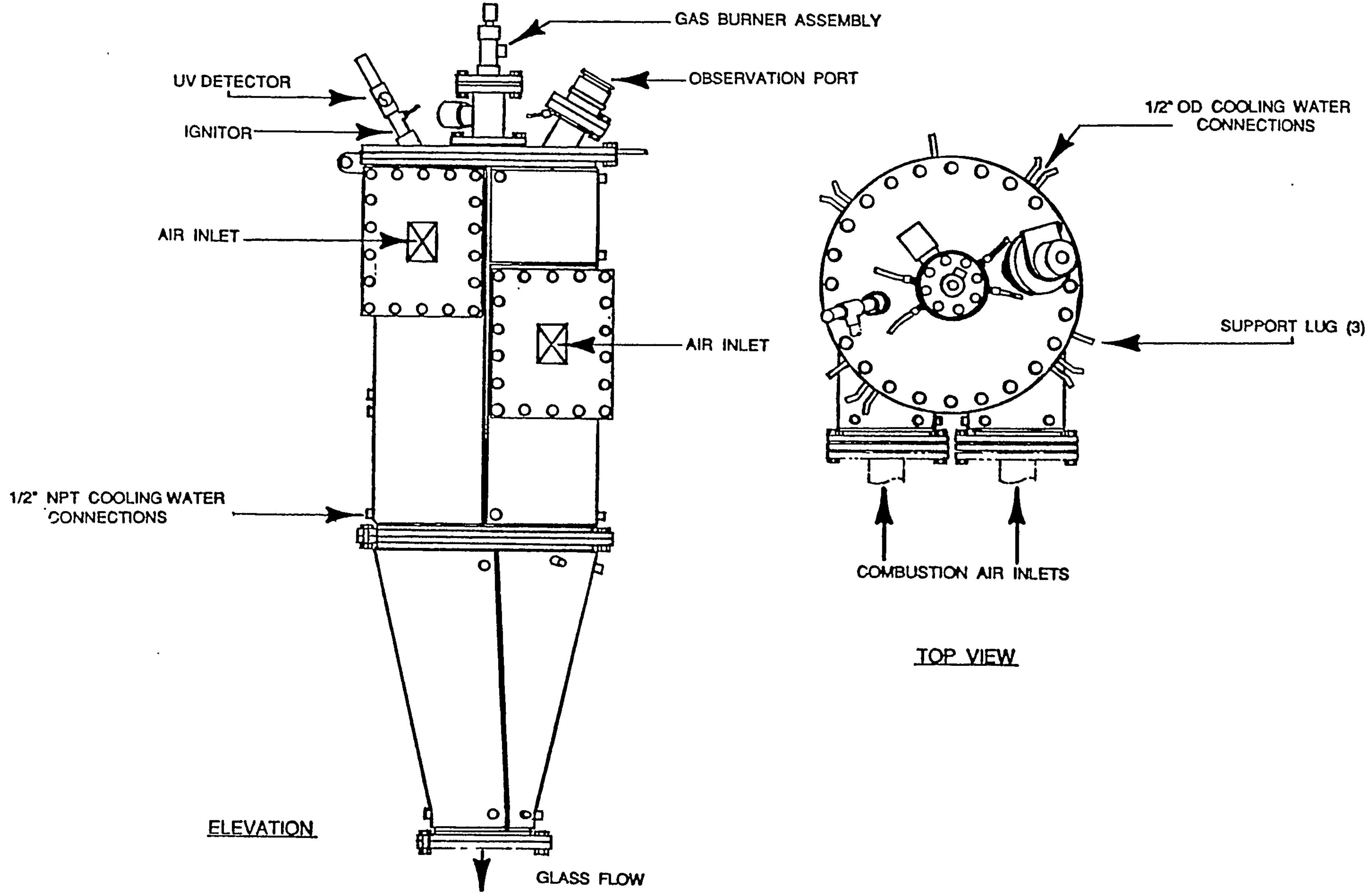


Figure 4.1-17
CRV Combustor Outline

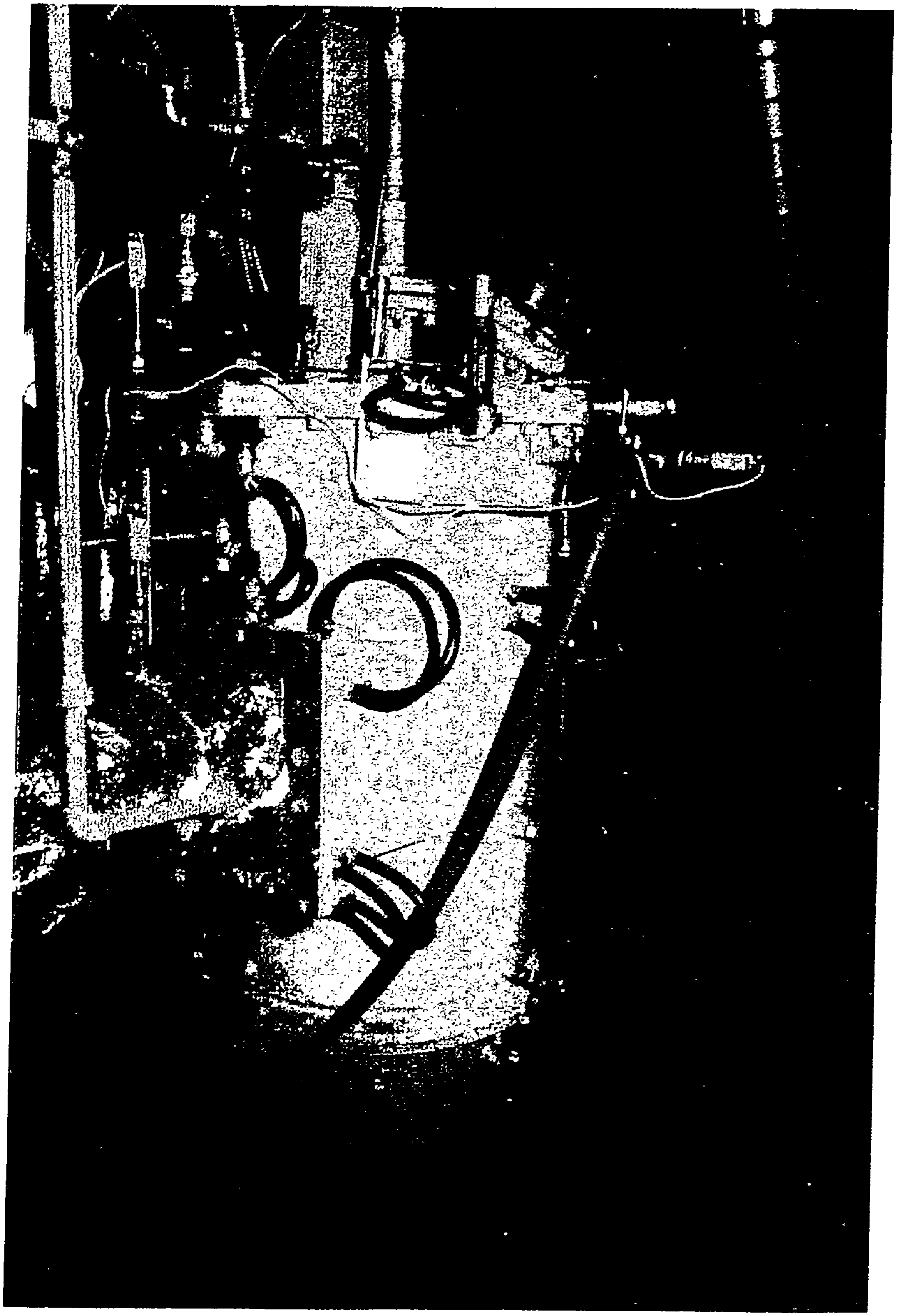


Figure 4.1-18
Pilot-Scale CRV Combustor Photograph

There are four refractory sections which make up the interior of the CRV combustor. Refractory inserts in the two tangential inlet sections can be changed to accommodate different inlet velocities for optimization of mixing, combustion, and flow patterns.

A 3 inch blast-gate observation port is located at the top of the CRV combustor to view the combustion/mixing process.

A water-cooled dual fuel injector is provided at the top of the CRV combustor. The entire assembly is approximately 4 inches in diameter. The injector is started/stopped manually; regulation is automatic with associated interlocks and alarms. The injector was designed by Vortec Corporation; however, the natural gas controls and the flame management system are commercially available systems provided by Bloom Engineering.

The natural gas safety controls consist of a double block and vent valve arrangement. Flame safety is provided by a Honeywell Blue Chip microprocessor and a Honeywell C7106 UV detector with self-checking circuitry. Natural gas will automatically trip on high/low gas pressure, loss of combustion air, loss of flame, and loss of cooling water. Coal feed will automatically trip on loss of combustion air, loss of flame, and loss of cooling water.

Start-up of the CRV combustor in the direct fired mode is initiated by a push button in the control room. Start-up is controlled by the flame management system which provides the necessary purge and flame detection for the CRV combustor.

A 100,000 Btu/hr commercial pilot burner supplied by Bloom Engineering is natural gas fired, and is also located at the top of the CRV combustor. It is used to ignite the main flame in the direct fired mode, and is manually started, but regulation is automatic, along with associated interlocks and alarms. A UV-type flame detector located within the pilot assembly provides verification of a stable flame, and provides an interlock to disable fuel supply in the event of a flameout. In addition, permissive circuitry allows opening of the main gas valve or initiation of the coal feed only when the pilot is "on". The flame safety system is also a commercial system supplied by Bloom Engineering.

4.1.4.3 Cyclone Melter

The function of the cyclone melter is to bring glass forming ingredients into close physical contact with each other to promote glass forming reactions and also separate the glass from the flue gas by centrifugal action. The melter has a throughput capacity of nominally 1000 to 2000 lb/hr.

The cyclone melter is a horizontally oriented, refractory lined, water jacketed cylindrical vessel. The steel shell is protected by a light-weight castable insulation and a 4 inch layer of abrasion resistant refractory lining. An outline of the cyclone melter is shown in Figure 4.1-19 and a photograph of the pilot-scale melter is shown in Figure 4.1-20. Cooling is provided within the water jacket to maintain metal skin temperatures below 200°F. A 3 inch blast gate observation port is provided.

The batch/flue gas combination enters the melter through a vertical inlet nozzle, leaves through a horizontal exit channel and enters the separator reservoir described below.

4.1.5 Separator/Reservoir

The functions of the separator/reservoir are: to complete the separation of glass product from the flue gas; to provide additional residence time to allow gas bubbles in the glass to rise to the surface and be freed from the molten glass, and to provide an extraction point for the product.

An outline of the separator/reservoir used in Phase III is shown in Figure 4.1-21 and a photograph of the pilot-scale unit is shown in Figure 4.1-22. The separator/reservoir, in plan view, is a "T" shaped, refractory lined vessel. The refractory lining, which consists of Fiberfrax Duraboard 2600, insulating firebrick, and Zedmark 30 refractory, provides a three-layer protection from heat and abrasion.

The entry to the separator/reservoir is followed by a larger, low velocity section serving to assist gravity separation of the glass from the gas. Further downstream, the glass and flue gas impacts upon a wall, thus separating any remaining glass product from the flue gas. The flue gas then turns horizontally and exits the separator/reservoir through a rectangular outlet into a horizontally oriented water spray quench assembly, described later.

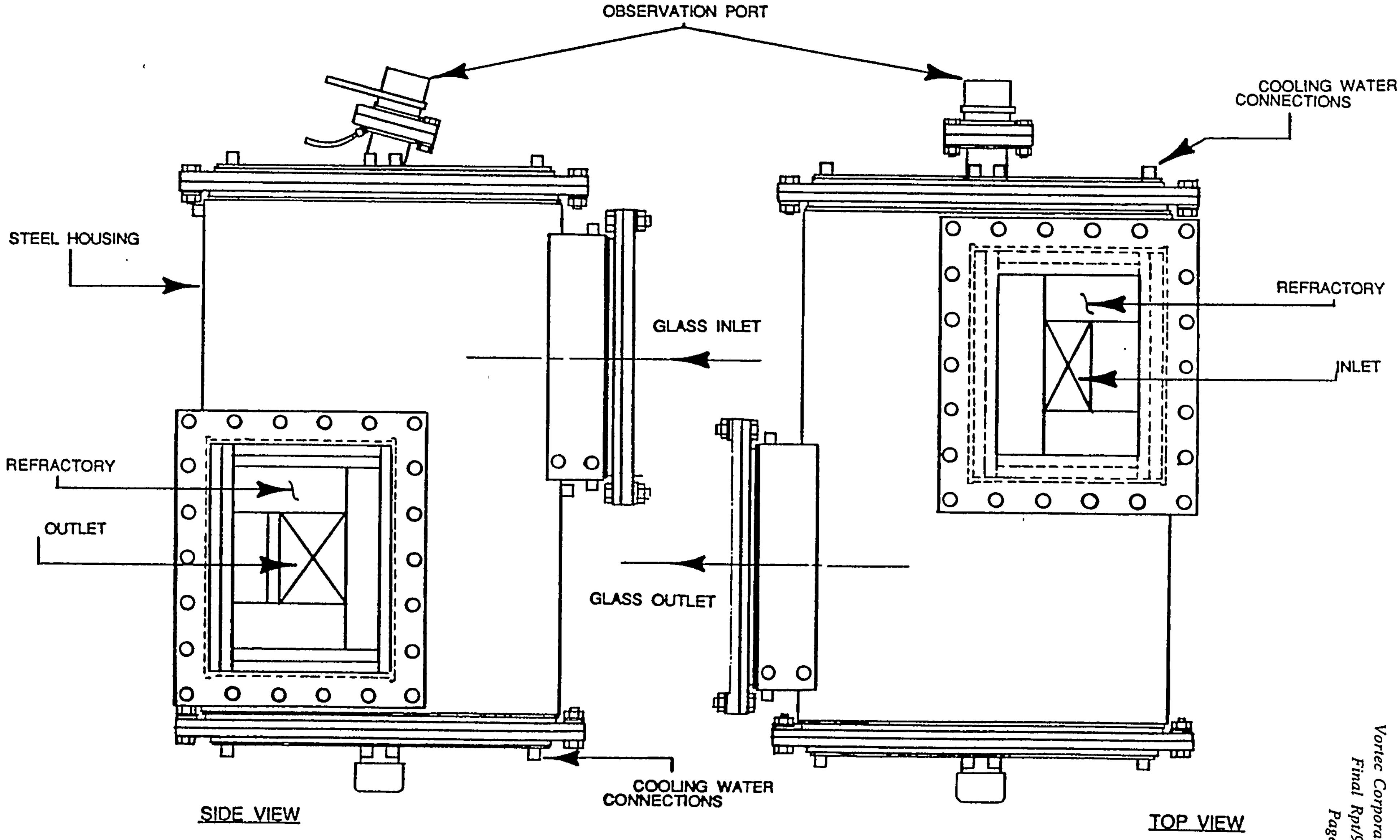


Figure 4-1-19
Cyclone Melter Outline

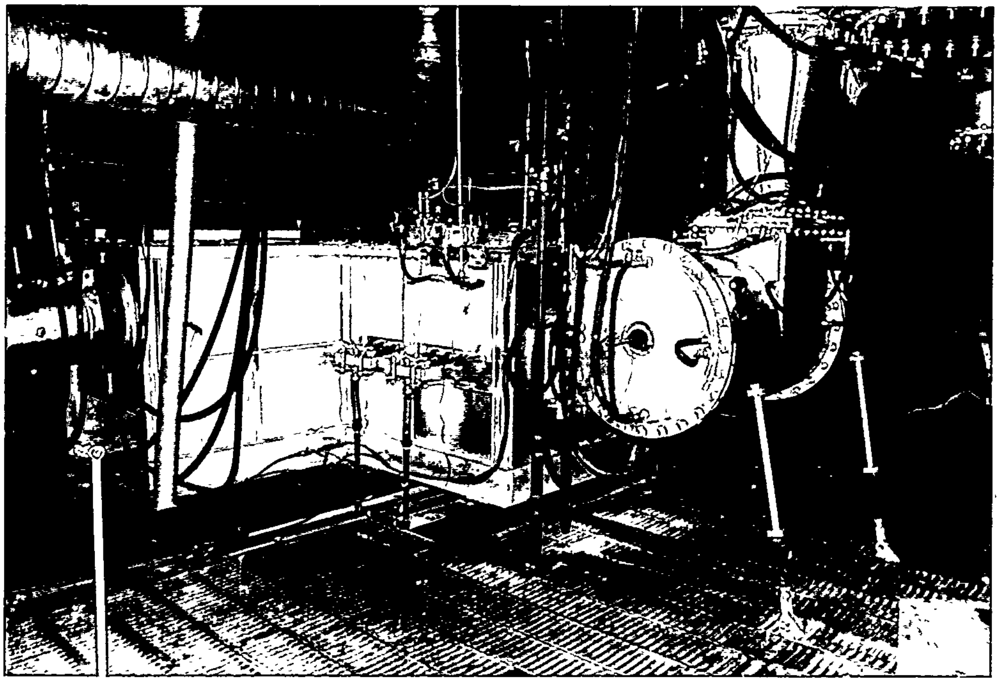


Figure 4.1-20
Pilot-Scale Cyclone Melter Photograph

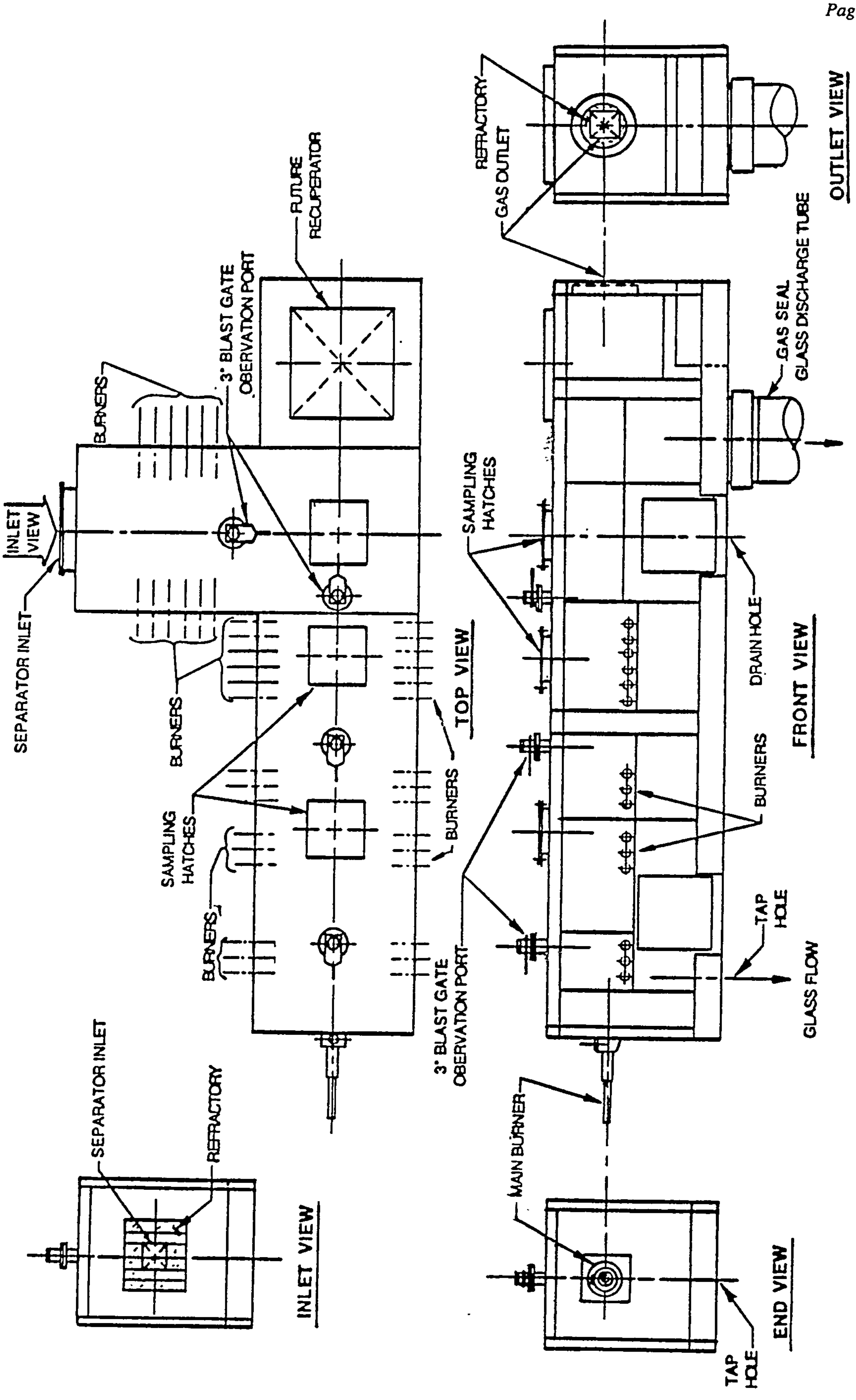


Figure 4.1-21
Separator/Reservoir Outline

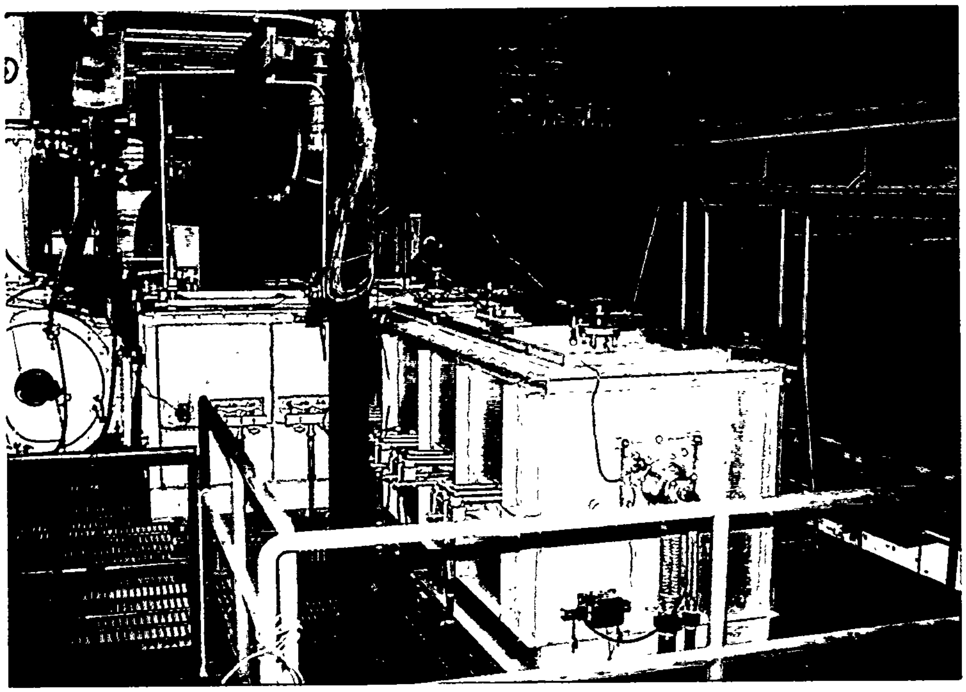


Figure 4.1-22
Separator/Reservoir in Pilot Scale Test System

Molten glass flows into a channel which is "L" shaped in the plan view. At the far end of the channel is a weir which determines the glass depth in the channel. As glass overflows the weir, it passes through the tap hole, flows down a cullet chute, and is quenched in a water filled dumpster. Depending on the flow rate, the channel provides up to four hoursof residence time for fining the glass. To prevent hot glass from flowing on top of cooler glass, skimmer bars have been placed across the channel and extend about half-way into the glass depth. As a result, cooler glass should be pulled from the bottom of one section into the next section as the glass flows down the channel.

Several inches above the glass surface is a combustion system which serves two purposes: a) it makes up for the structural heat losses through the walls of the separator/reservoir, and b) conditions or tempers the glass temperature by either controlling the cool down rate of the glass as it flows through the channel or by adding heat to the glass to raise its temperature. There are 42 premix burners each with a nominal capacity of 20,000 Btu/hr. Typically the energy utilization for glass conditioning is 10% to 20% of the thermal input requirement for glass melting operation. The thermal input for glass conditioning is not included in the glass melting heat rate data presented in this report. The burners and their manifolds are commercial items for the glass industry supplied by Emhart Glass. The gas controls and the combustion air blower were purchased as a package from Eclipse Combustion. The system will trip on low/high gas pressure and on loss of combustion air.

Traditionally, burner systems of this type use no flame detectors as gas is not turned on until auto-ignition temperatures are reached.

Located above the tap hole is a one million Btu/hr burner used for preheating the refractory during start-up of the separator/reservoir. The burner and it's burner management system are a stand alone system. The burner system will trip on loss of flame, high/low gas pressure, and loss of combustion air. This system is not fired during normal operation of the separator/reservoir.

Two additional drain holes are provided in the glass channel to drain the separator/reservoir at the end of a test run. A drain can also be utilized as a tap hole for short duration tests when filling the reservoir is not desired.

4.1.6 Flue Gas Cleanup System

Phase III testing showed that the wet venturi scrubber used in Test Loop "3A" was not adequate for collecting sub-micron particulate that was produced in the waste vitrification experiments. As a result, Test Loop "3B" was created to add a wet electrostatic precipitator (WESP) to the back end of the process for better particulate control. The following discussions describe both air pollution cleanup systems utilized during Phase III.

Test Loop "3A" Flue Gas Cleanup System

In Test Loop "3A" the flue gas cleanup system, shown in Figure 4.1-23, consists of the spray channel assembly, a wet venturi scrubber, a scrubber water recirculation tank, a pump, an ID fan, and a stack. The spray channel assembly consists of a 5 ft. long, 16 in. diameter channel, with 8 spray nozzles. Flue gases ranging in temperature from 2100° to 2500°F pass through the spray channel and are quenched to 200° to 300°F. The flue gases then exit through a 12 in. diameter side exit to the scrubber. At the end of the spray channel is a 3 in. diameter blast gate/observation port to view possible particulate build up within the spray channel. Any build up which may occur can be rodded out through the blast gate after removing the observation port. Unevaporated quench water runs down the inclined channel and drains into the scrubber via the 12 in. diameter exit. Spray water flow requirement is 10 gpm.

Flue gas scrubbing for particulate clean up is by a Fisher-Klosterman Model MS-250 wet scrubber. The scrubber is fitted with fog nozzles for dispersion of the scrubber water in the variable venturi inlet. Water requirement for effective scrubbing is 17 gpm. At a design flow of 3200 acfm and with a 10 in. w.g. differential pressure across the unit, the rated collection efficiency by weight is 99.55% of particles 2 microns and larger.

Both spray water and scrubber water drain to a 300 gallon recirculation tank. A series of baffles within the recirculation tank prevent the incoming water from agitating the whole tank. About 200 gallons of the tank is relatively undisturbed and allows larger particulate to settle out before the water is recirculated. A wire mesh strainer between the tank and the recirculation pump filters out particles that would erode the nozzles in the spray channel and the scrubber. The recirculation pump is a cast iron bronze fitted pump which supplies 37 gpm at 60 psig. City water make up is controlled by a float valve to maintain a constant water level in the recirculation tank.

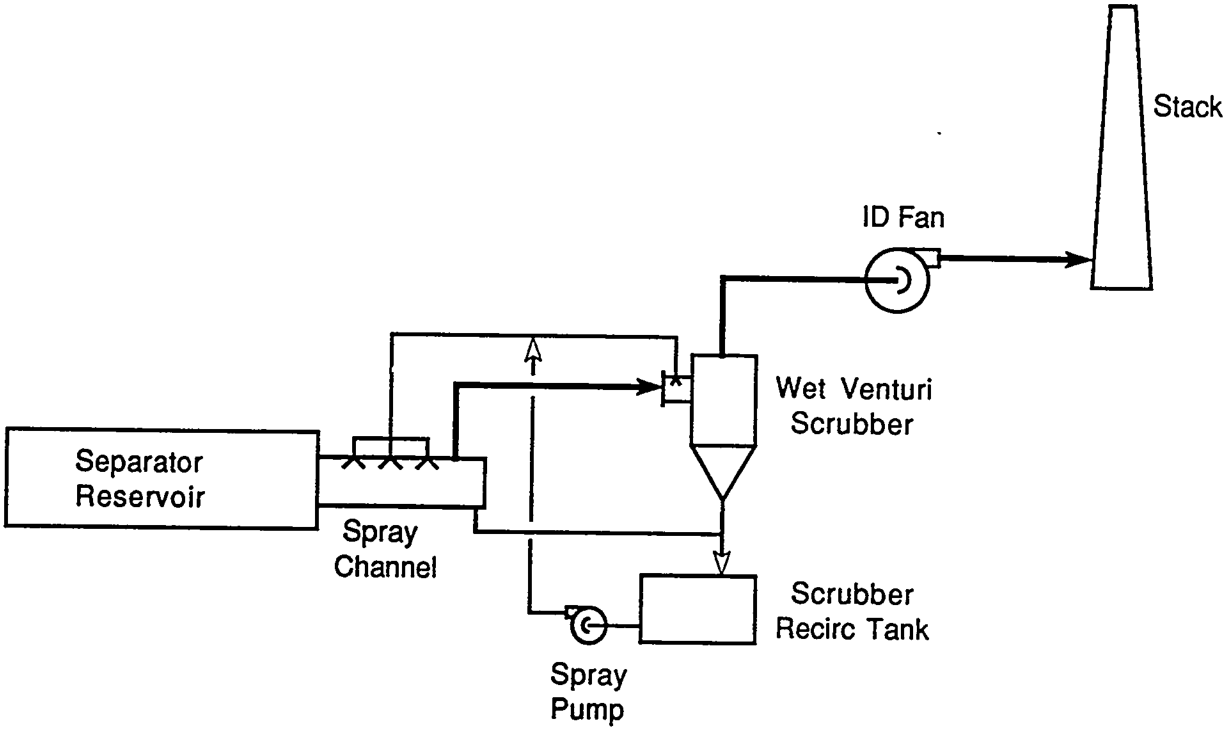


Figure 4.1-23
Test Loop "3A" Flue Gas Cleanup System

The flue gas/steam flow is exhausted from the system to atmosphere by an induced draft fan located at level 5 (914'-10") elevation and through a 12 inch diameter galvanized metal stack. The ID fan assembly is supplied by Twin City Fan and Blower, and is shown in Figure 4.1-24.

Test Loop "3B" and "3C" Flue Gas Cleanup System

In Test Loop "3B" and "3C" the flue gas cleanup system, shown in Figure 4.1-25, consists of a rod deck scrubber, a wet electrostatic precipitator (WESP), a WESP water recirculation tank, a pump, an ID fan, and another stack added in parallel to the existing cleanup system. As shown in the diagram, the spray channel is common to both cleanup systems. The cooled flue gases now leave the spray channel and pass to the rod deck scrubber. The WESP is shown in the photograph in Figure 4.1-26.

A WESP is very efficient in collecting water droplets, if particulate passing through the WESP is uniformly coated with water. The rod deck scrubber contains a fogging spray to initially wet the particulate and to cause some of the particulate, particularly the larger particulate, to fall out of the flue gas stream prior to entering the WESP. Any excess water with particulate flows from the rod deck scrubber into the WESP hopper bottom.

The flue gas enters the WESP at the bottom of the unit and flows upward through a fogging spray. The fogging spray is a fine mist which assures that the particulate is fully coated with water. The water droplets with the entrained particulate passes upward through the collection area, which consists of 116 - 6" hexagonal x 60" long collecting tubes, providing a total collection area of 1004 sq ft. Located in the center of each collecting tube is an electrode which sets up an electrostatic field between it and the collecting plate. The electrostatic field charges the water droplets, after which they are attracted to and collected by the collector plates. As water rolls down the collector plates it will effectively clean the plates. If additional cleaning is required, spray nozzles located above the collectors can be turned on to wash the plates with water. Particulate laden water falls from the collecting plates to the WESP hopper bottom.

The recirculation water system for the WESP is located in a building adjacent to the high bay area. The building contains two 1200 gallon recirculation tanks, two duplex strainers, and two supply pumps. A series of baffles within the recirculation tank prevents the incoming water from agitating the whole tank. About 1100 gallons of the tank is relatively

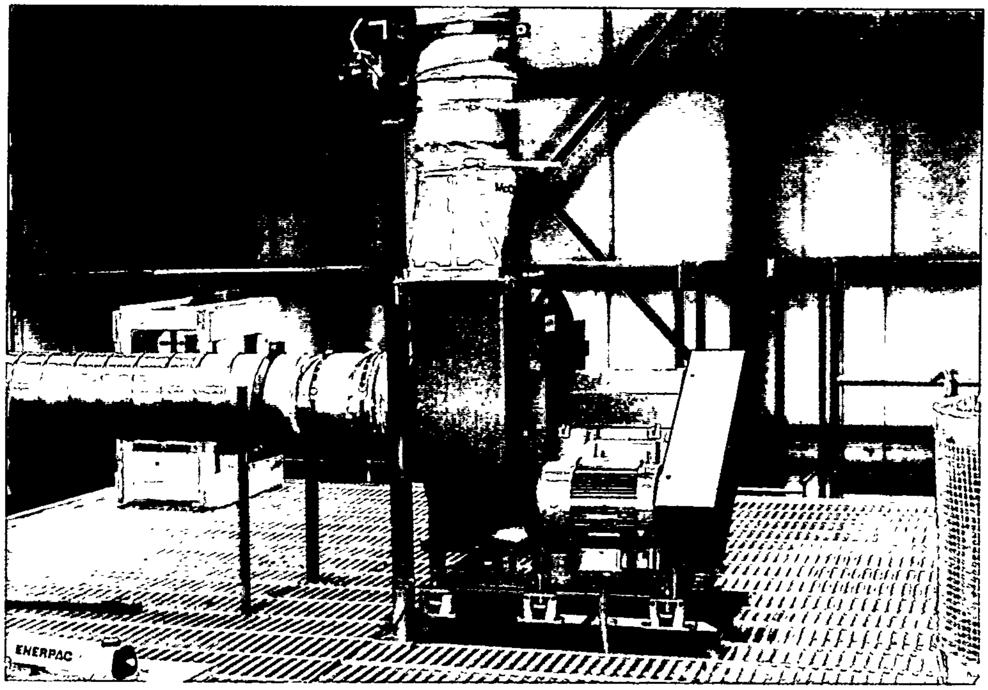


Figure 4.1-24
Induced Draft Fan Assembly in Pilot Scale Test System

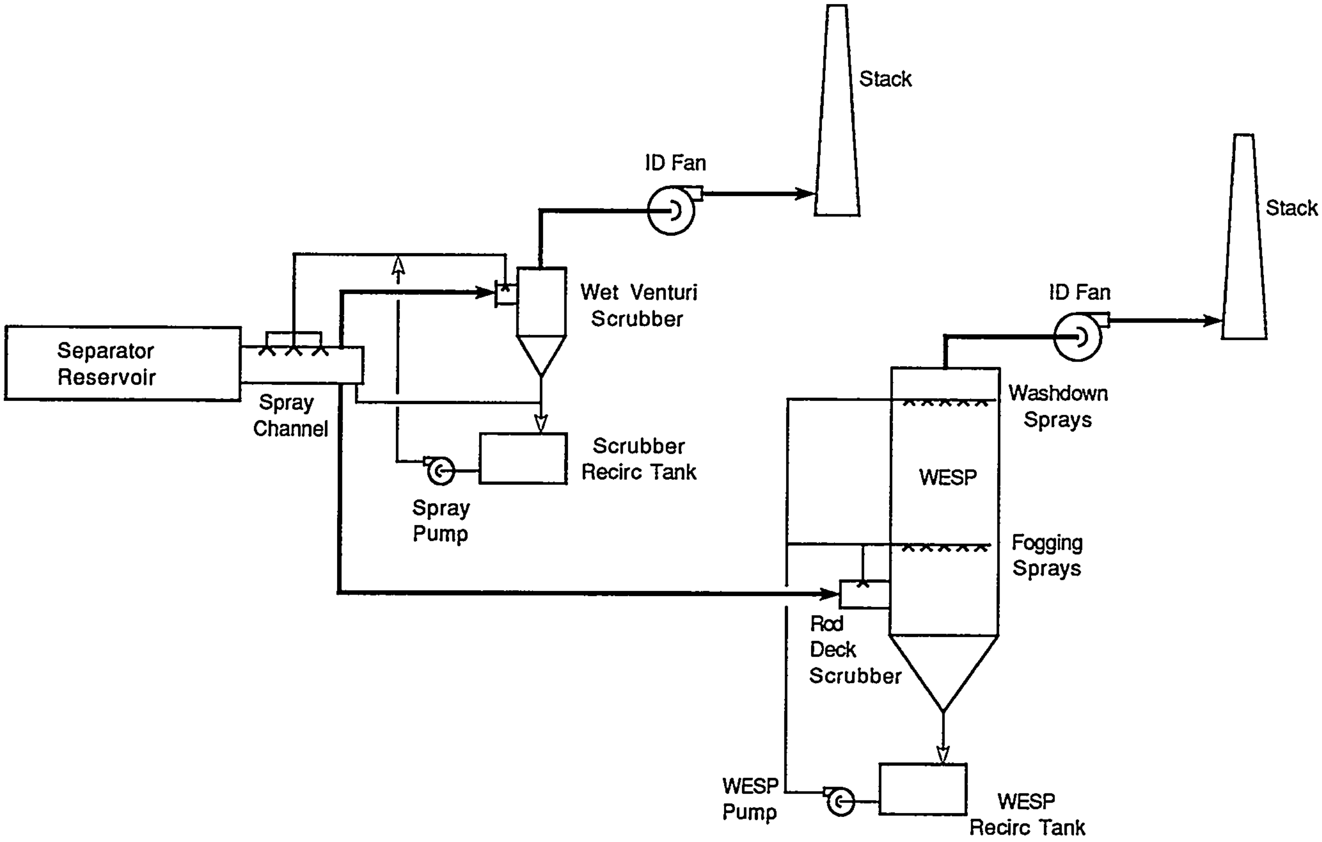


Figure 4.1-25
Test Loop "3B' and "3C" Flue Gas Cleanup System

Figure 4.1-26
Wet Electrostatic Precipitator in Pilot Scale Test System

undisturbed and allows larger particulate to settle out before the water is recirculated. A wire mesh strainer between the tank and the recirculation pump filters out particles that would erode the nozzles in the WESP and rod deck scrubber. The water is carried to the WESP via a 2-1/2" carbon steel pipe. At the WESP, water is delivered to the rod deck scrubber, the fogging headers, and the wash headers. Water inside the WESP is collected in the base of the WESP. The return water passes from the bottom of the WESP to two return pumps located at the base of the WESP. The return pumps deliver the water back to the recirculation tanks by a 2-1/2" carbon steel pipe.

Flue gases exit the WESP, pass through the ID fan, and are discharged to atmosphere by the stack. As shown in the diagram, the facility has two ID fans and two stacks. Dampers at the ID fans can be closed to control the flow of gases through each system.

4.1.7 Cooling Water System

Cooling water for the test loop is supplied by a 3 inch line from the U-PARC pond water supply. Water enters the building through a main shutoff valve, passes through a pressure regulator to a flow switch, and is then manifolded to 22 segregated cooling water circuits. The manifold provides sixteen circuits to the CRV combustor, three circuits to the cyclone melter, and three circuits to the separator/reservoir. Flows and temperatures are controlled and monitored in each individual circuit. A flow switch in the cooling water circuit interlocks the cooling water with the combustion system. Cooling water must be flowing in order to start the pilot burners or main flame. Loss of cooling water flow will automatically trip gas flow and coal feed.

Each cooling water circuit is controlled by it's own manual globe valve. The globe valves have a drilled bypass to insure a safe level of water flow in each circuit in the case of an inadvertent closing of a valve. Inlet water temperature is monitored by one thermocouple in the inlet water header. Water temperature for each circuit is monitored by a thermocouple on the outlet side. Abnormal water outlet temperatures are an indication of refractory/vessel wall or cooling system failure, and may require a unit shut down if the problem cannot be corrected.

Cooling water is cross connected to the city water system to allow for safe shutdown should the U-PARC pond water supply fail. The city water will automatically come on should cooling water pressure drop below 20 psig. A backflow preventer is present in the "cross-connect" to prevent possible contamination of the city water by the cooling water.

4.1.8 Process Control System

The process control system contains both manual and automatic features. The initiation of each process subsystem is manual, but the operator is required to engage the operation of each subsystem in a specified sequence. Following this initiation, the operation of each subsystem will be automatic to maintain an entered setpoint.

The heart of the control system is a 486 personal computer which is dedicated to operating the Genesis control series program. The computer communicates with the subsystems through digital and analog input/output and data highway communications cards.
The Genesis control series program uses drivers to facilitate communications between the computer and the input/output hardware connections. Using available data, Genesis runs a developed control strategy designed to provide the following functions: data acquisition, recording, trending, mathematics, logics, indication, status, digital control, analog control, alarming, sequencing, timing, reporting, and user intervention.

The control system set-up and the control panels for the pilot scale system are shown in the photographs in Figures 4.1-27(a) and (b). The process control system also includes a data acquisition or "data logging" capabilities for automatic recording of various process system variables such as: pressures, temperatures, and flowrates. During start-up operations, data is typically recorded once every five minutes, and during actual test operations, it is recorded once every minute. Some variables, such as cooling water flows, remain constant during a test run; these variables are recorded manually, as directed by the test engineer. A summary of the test variables that are recorded, the instrument used for obtaining the reading, the location of the measurement, and how it is recorded are provided in Table 4.1-1.

4.1.9 Flue Gas Sampling And Analysis

Hot flue gases for analysis can be withdrawn from either the inlet to the separator/reservoir or from the spray channel between the separator/reservoir outlet and the water spray. The

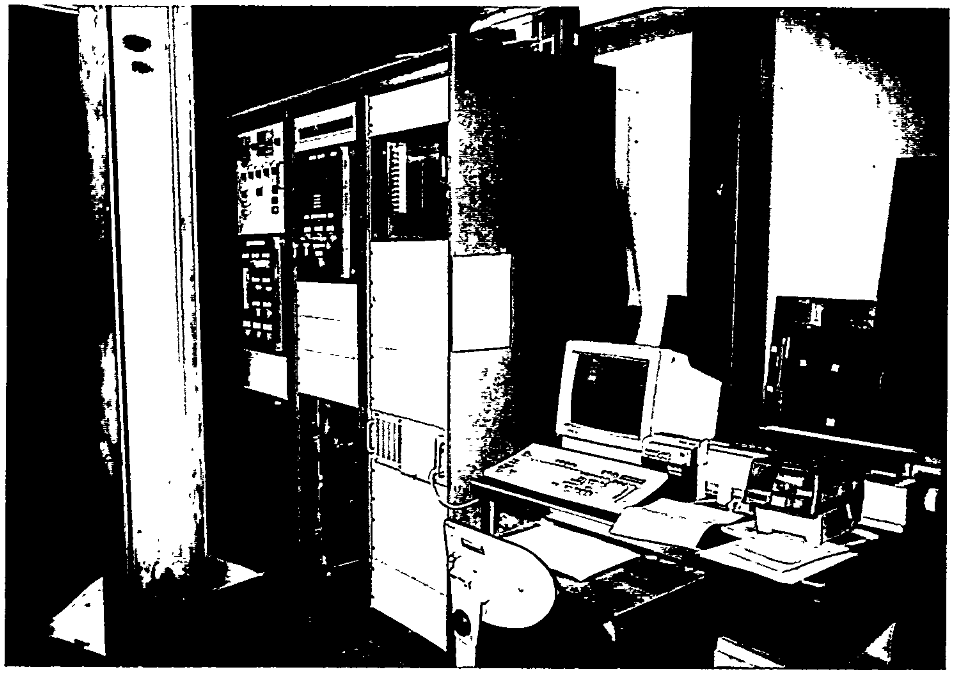


Figure 4.1-27(a)
Control System

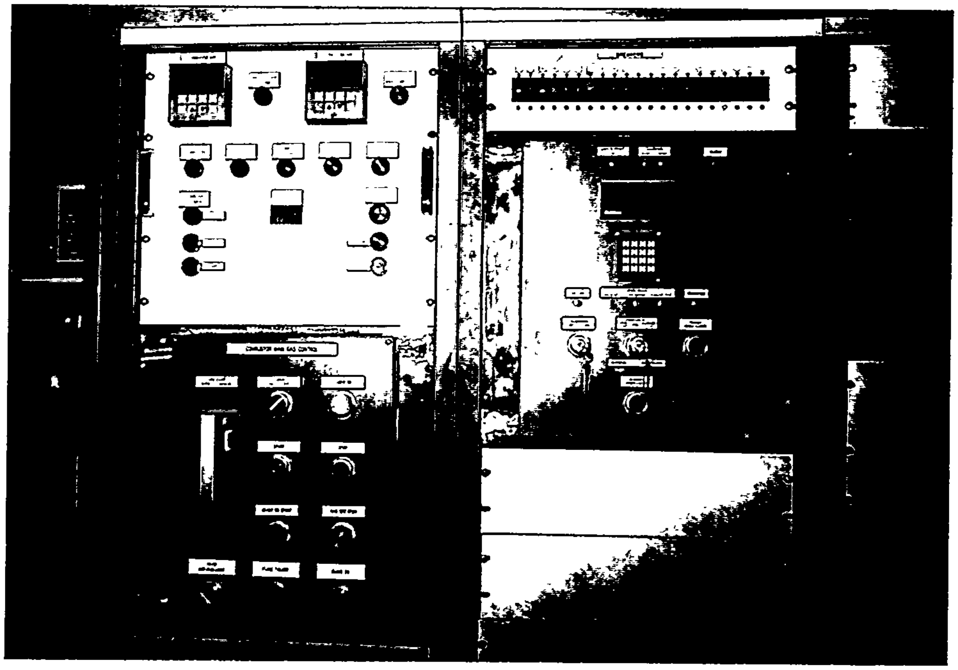


Figure 4.1-27(b)
Manual Control Panel

Table 4.1-1
Instrumentation Summary

System/Component	Measurement	Instrument	Location	Recorded by
Process Air Supply and Preheat System				
Lamson Blower	Pressure	Pressure Transmitter	Blower outlet	Data Logger
		Pressure Guage		Reference only
	Temperature	K thermocouple	Blower outlet	Data Logger
		Dial thermometer		Reference only
	Flow	Orifice plate	Blower Outlet	Data Logger
Air Heater	Temperature	K thermocouple	Heater outlet	Data Logger
Coal Supply/ Feed System				
Coal Tank	Weight	Load cells	Tank supports	Data Logger
	Coal Flow	Load cells	Tank supports	Manual - loss in weight calc.
Transport Air	Pressure	Pressure transmitter	Air supply line	Data Logger
	Temperature	K thermocouple	Air supply line	Data Logger
	Flow	Orifice plate	Air supply line	Data Logger
Batch Supply/ Feed System				
Batch Tank	Weight	Load cells	Tank supports	Data Logger
	Coal Flow	Load cells	Tank supports	Manual - loss in weight calc.
Transport Air	Pressure	Pressure transmitter	Air supply line	Data Logger
	Temperature	K thermocouple	Air supply line	Data Logger
	Flow	Orifice plate	Air supply line	Data Logger
CMS				
Coal Fired Precombustor	Inlet Air Temperature	K Thermocouple	Inlet arm	Data Logger
	Inlet Air Pressure	Pressure transmitter	Inlet arm	Data Logger
	Refractory Temperature	S Thermocouples	Embedded in refractory	Data Logger
	Gas Temperature	S Thermocouple	Combustor sidewall	Data Logger
	Gas Pressure	Pressure transmitter	Viewport	Data Logger
CRV	Gas Temperature	S Thermocouple	Inlet arm	Data Logger
		S Thermocouple	Combustor sidewall	Data Logger
		S Thermocouple	CRV outlet	Data Logger
	Gas Pressure	Pressure transmitter	Viewport	Data Logger
	Refractory Temperature	S Thermocouples	Embedded in refractory at CRV outlet	Data Logger
Cyclone Melter	Gas Temperature	S Thermocouple	Cyclone melter endwall	Data Logger
	Gas Pressure	Pressure transmitter	Viewport	Data Logger
Natural Gas	Pressure	Pressure transmitter	Process gas supply line	Data Logger
	Temperature	K thermocouple	Process gas supply line	Data Logger
	Flow	Orifice plate	Process gas supply line	Data Logger

Table 4.1-1 (cont'd)
Instrumentation Summary

System/Component	Measurement	Instrument	Location	Recorded by
Separation Chamber				
	Gas Temperature	S Thermocouple	Inlet	Data Logger
	Refractory Temperature	S Thermocouples	Embedded in refractory	Data Logger
	Glass temperature	S Thermocouples	Tap hole block	Data Logger
	Gas Pressure	Pressure transmitter	Viewport	Data Logger
Separator/Reservoir				
	Gas Temperature	S Thermocouple	Inlet	Data Logger
	Refractory Temperature	S Thermocouples	Embedded in refractory	Data Logger
	Glass temperature	S Thermocouples	Tap hole block	Data Logger
	Gas Pressure	Pressure transmitter	Viewport	Data Logger
Natural gas	Pressure	Pressure transmitter	Burner gas supply line	Data Logger
	Temperature	K thermocouple	Burner gas supply line	Data Logger
	Flow	Orifice plate	Burner gas supply line	Data Logger
Combustion air	Pressure	Pressure transmitter	Eclipse blower outlet	Data Logger
	Temperature	K thermocouple	Eclipse blower outlet	Data Logger
	Flow	Orifice plate	Eclipse blower outlet	Data Logger
Flue Gas/Quench System				
	Flue gas temperature	S Thermocouple	Spray channel inlet	Data logger
		K Thermocouple	Scrubber outlet	Data logger
		Dial thermometer	Scrubber outlet	Reference
	Excess oxygen	Beckmann Model 755 Oxygen Analyzer	Spray Channel Inlet	Data Logger
	CO	Beckmann Model 870 Non-Dispersive Infrared Analyzer	Spray Channel Inlet	Data Logger
	NO/NOx	Beckmann Model 951A NO/NOx Analyzer	Spray Channel Inlet	Data Logger
	SOx	Beckmann Model 880 Non-Dispersive Infrared Analyzer	Spray Channel Inlet	Data Logger
Cooling Water System				
Global view	Supply Temperature	K Thermocouple	Supply water header	Data Logger
		Dial Thermometer	Supply water header	Manual
	Ave. return temperature	K Thermocouple	Return water header	Data Logger
Individual circuit	Temperature	K Thermocouple	Component exit	Data Logger
		Dial Thermometer	Component exit	Manual
	Flow	Rotameter	Component entrance	Manual

flue gases are drawn through a water cooled probe, a Pall Trinity sintered metal filter, and a refrigerated cooler by a small sample pump. The gases leave the sample pump, pass through another refrigerated cooler and a Perma Pure filter, and then pass on to the analyzers located in the control room. In the control room are four Rosemount Analytical/Beckman analyzers for monitoring oxygen, carbon monoxide, sulphur dioxide and NO/NO_X. Each instrument provides an analog output for automatic data logging by the process control system.

Particulate measurements in the stack are made with an Andersen Instruments Inc. Universal Stack Sampler.

4.1.10 Facility Services

Services existing at the U-PARC Complex include natural gas, shop air, instrument air, service cooling water, city water, and electrical supply, and are described in the following sections:

4.1.10.1 Natural Gas

Natural Gas is supplied by U-PARC at 8 psig through a 2-1/2 inch diameter underground line. The line comes above ground at the northwest side of the air heater, and is supplied to the unit through a gas cock.

The 2-1/2 inch line continues upward through a shutoff valve, then runs overhead in a southerly direction into building B11. The line penetrates building B11 between columns 3 and 4, then runs east along the wall to the test tower. Another manual shutoff valve is located at level 2 of the test tower.

4.1.10.2 Instrument/Service Air Supply

A Sullair Model 10 (30 HP) rotary screw compressor, shown in Figure 4.1-28, supplies 120 ICFM of air at 115 psig for service air and transport air for the process. The air passes through two Zeks prefilters (a coalescing filter and a particle filter) prior to entering a Zeks Model NCB 100 refrigerant air dryer which reduces the dew point of the 115 psig air to 35°F (approximately -40°F at STP).

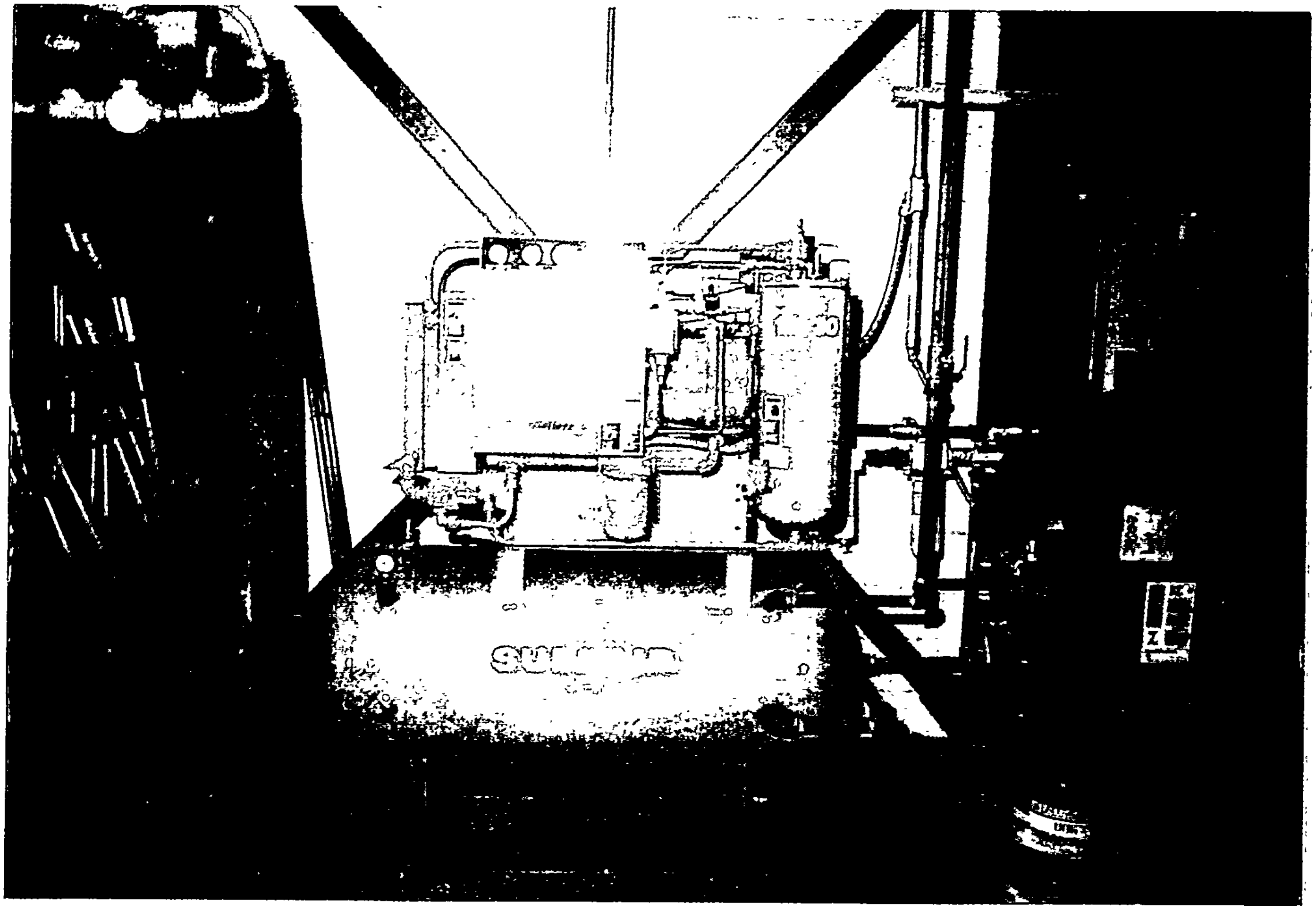


Figure 4.1-28
Air Supply Compressor for Service and Transport Air

The U-PARC house service air line is tied into the air receiver via a 1 inch pressure reducing valve set at 80 psig. Should the pressure in the air receiver fall below 80 psig, the U-PARC air system will act as a backup to allow a safe shut-down of the process.

4.1.10.3 Water Supply

U-PARC supplied pond water for cooling purposes flows through 3 inch pipes along the north wall of building B11, with a pipe station located in bay AB34. City water for spray cooling, and other purposes, runs in 2 inch pipes, also along the north wall.

4.2 SYSTEM TEST OPERATIONS

4.2.1 Preliminary System Tests

During Phase III of the program, nine major preliminary tests (Tests 29 to 34, 37, 42, and 45) were conducted under the DOE/PETC contract with the objectives of validating the operation of the basic process components, identifying significant potential markets for the technology, obtaining baseline information on the melting performance of the candidate waste materials to be processed later under the proof of concept testing, and to characterize flue gas emissions for future installation of supplemental air pollution control equipment. The tests also provided the opportunity to present the technology to potential industrial partners and users, which resulted in teaming arrangements with three cost sharing partners.

Prior to the initiation of preliminary tests, NEPA documentation was prepared for DOE and approval for the performance of tests under the contract was received from DOE. During the period of time that the NEPA documentation was reviewed, the cyclone melter and separator/reservoir in the test system were relined. The following sections present summaries of the preliminary tests.

4.2.1.1 Tests 29-34

A total of 38 hours of process heating operation were accumulated during these preliminary test runs with natural gas as the primary fuel. Table 4.2-1 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

Table 4.2-1 Principal Test Parameters of Tests 29 - 34

Test Run No.	Date	Fuel Type	Combustion Air			Feedstock		Test Length	Glass		Emissions					Heat	Rate
			Nominal Rate (MMBtu/Hr)	Excess Air (Nominal)	Preheat Temp. (Nominal. °F)	Type	Rate (lb/hr)	Test Duration (hrs)	Qty Melted (lbs)	Glass Temp (°F)	O2 (%)	NOx (ppmv)	SO2 (ppmv)	CO (ppmv)	Particulates % of Feed	MMBtu ton of batch	MMBtu ton of glass
29	9/16/91	Natl. Gas	3.85	6%	1050	Duquesne 60% Utility FA 40% limestone 7% L.O.I.	778	10	7134	2700	1.3	264.2	107.5	515.7	2.28	9.9	12.66
30	10/10/91	Natl. Gas	4.02	24%	1100	Res Fiberglass 6% L.O.I.	1600	4	4287	2200-2300	8.7	NA	NA	47.3	7.77	5.03	5.35
31	4/29/92	Natl. Gas	3.691	31.40%	1102	Sewage Sludge Ash 5% L.O.I. 15% Water	961	7.5	3602	2320	5.0	168.9	19.78	1309	1.53	7.68	9.60
32	4/29/92	Natl. Gas	3.34	45%	1104	MSW Flyash Northeast 7.5% L.O.I. 0.5% Water	818	6	3644	2320	6.5	27.2	76.2	28.02	4.2	8.17	8.88
33	4/30/92	Natl. Gas	3.542	40%	1103.5	Consumer Waste Cullet	1034	4.5	4160	2310	6.0	82.1	4.2	1567.3	0.38	6.85	6.88
34	6/17/92	Natl. Gas & Oxygen	3.185	43%	1071	Consumer Waste Cullet	1103	5	1714	2393	11.0	1296.9	14.8	127.1	NA	5.78	5.78

ssion data corrected to 3% oxygen, dry gas.
NA - Not Available

were performed by an independent environmental company. NO_x, 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 is 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. A 7.5 HP Palla vibrating ball mill and NBE 24 cu. ft. blender are also installed at the U-PARC facility for feedstock preparation.

Test 29

Test No. 29 examined the melting of a utility boiler flyash when blended with 40% limestone. The flyash utilized was obtained from the Duquesne Light Company Cheswick plant. The mixture ratio of 60% flyash-to-40% limestone was established based on the melting characteristics as determined by laboratory crucible melts and previous pilot scale test operations. 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. The NO_x, SO_2 and CO levels measured during the test were 264, 107 and 515 ppmv (corrected to 3% O_2, dry gas), respectively.

Test 30

Test No. 30 examined the vitrification/recycling of residential fiberglass wastes. The waste materials, and cost sharing support for the test were provided by a major glass manufacturer. Approximately 3.2 tons of residential insulation fiberglass batting with 3-6% binder, backed with kraft paper and asphalt adhesives were processed at an average feed rate of about 1600 lb/hr. One major objective of the test was to evaluate the oxidation/vitrification capacity of the Vortec CMS™ when processing waste insulation fiberglass materials. Because insulation fiberglass contains sodium and boron based species which tend to volatilize to some extent during glass melting operations, the partial volatilization of these species was anticipated. The measurement of the total particulate emissions was also another major test objective. To ensure the effective oxidation of the organics contained in the fiberglass binders, the excess air ratio was increased relative to the utility flyash material processed under Run No. 29. The pneumatic feeding system used to transport the waste material to the CMS™ accounted for a significant portion of the excess air delivered to the process. As a result of the glass fluxes contained in the waste material, the vitrified product formed had a relatively low melting temperature (i.e., ca. 2200 - 2300°F). NO_x and SO_2 measurements are not reported because of sampling and instrumentation problems. The recorded CO levels were measured to be 47 ppmv, suggesting good oxidation of the phenolic binders. The total uncontrolled particulate emissions are estimated to be 7.7% of the total feedstock input to the process. The particulate emissions were found to be predominantly less than 5 microns in size. The fuel inputs requirements for processing the waste material amounted to about 5 million Btu/ton of waste. Some of the energy requirements for processing the waste material were derived from oxidation of the phenolic binders, paper and asphalt contained in the insulation bats.

Test 31

Test Run 31 evaluated the vitrification of an incinerator ash generated by the incineration of sewage sludge. 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. TCLP tests performed with the sewage sludge incinerator flyash and vitrified product indicated that all the RCRA metals readily passed the leaching test requirements. During the testing of the sewage sludge ash, approximately 3600 lbs of ash were melted over a 7.5 hr test period. 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 NO_x, SO_2 and CO levels during the test run were measured to be 169, 20 and 1309 ppmv, respectively. The high CO level experienced during this test is thought to be caused by the high (15%) water content in the ash. In addition to the quenching effect of batch feed, evaporation of the water from the batch could further lower the flame temperature resulting in CO generation from the delayed ignition of the unburned carbon found in the ash (4.9%) and the natural gas fuel. The total uncontrolled particulate carryover was 1.53% of the feedstock feed rate. Most of the particulates were collected in the venturi scrubber (1.27% of feedstock) while 0.20% was carried over into the stack. The NO_x and SO_x emissions were measured to be 0.321 and 0.052 lb/million Btu, respectively.

Test 32

Test Run No. 32 evaluated the performance of the CMS™ when processing a municipal incinerator flyash. The flyash tested was from an incinerator located in the Northeastern section of the United States (NE-1). The average particle diameter of the NE-1 ash is approximately 70 microns with 90% being less than 250 microns. Compared to the coal-fired boiler flyash, the MSWI ash was found to have lower SiO_2 concentrations (29.5%), lower Al_2O_3 levels (11.6%), lower Fe_2O_3 levels (2.8%), higher CaO levels (28.2%) and higher K_2O/Na_2O concentrations (5.6% combined). The higher glass modifier concentrations in these ashes reduced the amount of additives required to achieve reasonable glass fluid properties. For the NE-1 ash with 28.2% CaO, no additional modifiers were required to suitably melt the flyash. Test operations with the NE-1 ash were performed at a feed rate of 818 lb/hr and thermal input of 3.41 mm Btu/hr. The uncontrolled particulate emissions amounted to 4.24% of the total feedstock input. The particulates collected in the venturi scrubber were 0.28% of the feed, while the stack emissions were 3.96%. The higher stack emissions for the MSWI are primarily due to the finer size distribution of the particulates generated during the vitrification of MSWI ash. It is conjectured that the finer size distribution of these particulates is due to volatilization and subsequent recondensation of chloride salts. Chemical compositions of the carryover collected in the scrubber and by the stack gas Method 5 sampling indicate that the scrubber sediment consisted primarily of SiO_2 (9.2%), Fe_2O_3 (4.4%) and PbO (40.5%). In contrast, the stack particulates had relatively high concentrations of K_2O (17.6%) and Na_2O (28.9%). The lead oxide concentration in the stack gas (5.2%) was considerably lower than in the scrubber sediment.

Tests 33 and 34

Test Runs No. 33 and 34 were conducted using a commercially processed container glass cullet which was spiked with metals to assess the ability of the CMS™ to oxidize metal contaminants and to assess the oxidation/redox state of the glass produced. The primary metal of concern is aluminum, since magnetic separation cannot be used with non-ferrous metals and the contaminant pieces are often too small to be effectively removed by eddy current separators. Test Run No. 33 was performed using combustion air preheated to 1100°F as the oxidizer. During this test run, a dark red cullet frit was produced suggesting that complete oxidation of the metals did not occur. Test Run No. 34 was essentially a repeat of the previous test, except oxygen enrichment was utilized to enhance the metal oxidation rates. During this second test run, there was a noticeable increase in the combustion intensity and temperature within the CRV combustor indicating an increase in the combustion intensity as a result of the increased oxygen concentration. The maximum oxygen enrichment level during the test run was 40%. The color of the frit produced was again dark suggesting that metal oxidation was not effectively completed. During both tests, the feedstock flow rates were in excess of 1000 lb/hr. With preheated air as the oxidizer, the NO_x, SO_2, and CO levels during Test Run No. 33 were measured to be 82, 4, and 1567 ppmv, respectively. The high CO level during this test can be attributed to contamination in the CO sampling train. The total uncontrolled particulate carryover was 0.38% of the feedstock feed rate. The heat rate for the test run was determined to be about 6.9 million Btu/ton with a glass melt temperature of 2310°F. During Test No. 34 when oxygen enrichment was utilized, the energy requirement for melting dropped to about 5.8 million Btu/ton and the CO emission levels were 127 ppmv. The NO_x emissions increase from 82 ppmv to 1296 ppmv can be attributed, in part, to the higher process temperatures as is evidenced by the elevated glass temperature. The slightly higher SO_2 level measured during the oxygen enrichment test (15 versus 4 ppmv) could possibly be attributed to slight variations in feedstock composition or an increase in the level of SO_2 outgassing from the glass as a result of the elevated glass melt temperature.

4.2.1.2 Tests 37, 42, 45

Test No. 37 used coal char/flyash from a coal-fired industrial boiler as the fuel/feedstock. A Loss on Ignition (LOI) analysis conducted on the feedstock indicated that the coal char/flyash feedstock contained approximately 38% by weight of unburned carbon. It was anticipated that this should provide sufficient thermal input so that no additional fuel would be required to vitrify the remaining inorganics. It was also anticipated that because of the low volatile nature of the coal, some oxygen enrichment may be necessary to complete the burnout of the char given the existing CRV combustor residence time.

Test No. 42, conducted in conjunction with a DOE SBIR program to evaluate the use of the CMS™ as a coal-fired sewer sludge vitrification system, used sewer sludge ash as the feedstock and a washed Upper Elkhorn coal as the fuel. Vortec had 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.

Test No. 45 evaluated injecting coal coaxially with feedstock directly into the CRV combustor. 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 combustor and to see if complete burnout of the coal can be obtained prior to interaction with the glass.

A total of 24 hours of coal-fired process heating operation were accumulated during the test runs. Table 4.2-2 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. NO_x, SO_2, O_2, CO_2 and CO measurements were measured by Vortec using an on-line emissions analysis sampling train.

Test No. 37

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

Table 4.2-2 Principal Test Parameters for Tests 37, 42, 45

Test Run No.	Date	Fuel Type	Combustion Air			Feedstock		Test Length	Glass		Emissions					Heat Rate	
			Nominal Rate (MMBtu/Hr)	Excess Air (Nominal)	Preheat Temp. (Nominal, °F)	Type	Rate (lb/hr)	Test Duration (hrs)	Qty Melted (lbs)	Glass Temp (°F)	O2 (%)	NOx (ppmv)	SO2 (ppmv)	CO (ppmv)	Particulates % of Feed	MMBtu ton of batch	MMBtu ton of glass
29	9/16/91	Natl. Gas	3.85	6%	1050	Duquesne 60% Utility FA 40% limestone 7% L.O.I.	778	10	7134	2700	1.3	264.2	107.5	515.7	2.28	9.9	12.66
30	10/10/91	Natl. Gas	4.02	24%	1100	Res Fiberglass 6% L.O.I.	1600	4	4287	2200-2300	8.7	NA	NA	47.3	7.77	5.03	5.35
31	4/29/92	Natl. Gas	3.691	31.40%	1102	Sewage Sludge Ash 5% L.O.I. 15% Water	961	7.5	3602	2320	5.0	168.9	19.78	1309	1.53	7.68	9.60
32	4/29/92	Natl. Gas	3.34	45%	1104	MSW Flyash Northeast 7.5% L.O.I. 0.5% Water	818	6	3644	2320	6.5	27.2	76.2	28.02	4.2	8.17	8.88
33	4/30/92	Natl. Gas	3.542	40%	1103.5	Consumer Waste Cullet	1034	4.5	4160	2310	6.0	82.1	4.2	1567.3	0.38	6.85	6.88
34	6/17/92	Natl. Gas & Oxygen	3.185	43%	1071	Consumer Waste Cullet	1103	5	1714	2393	11.0	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+	3.2	264	107	515	2.28%	3.75**	3.75**
42	9/16/92	Coal U. Elkhorn	2.4	10%	1080	Sewer Sludge Ash (Alcosan)	680	6	3250	2500	5.4	425	225	112	1.50%	7.05	7.05
45	9/17/92	Coal	1.7	10%	1075	Cullet	980	5	4300	2100	8.1	200	130	80	1.00%	3.5	3.5

ission data corrected to 3% oxygen, dry gas
hermal Input From Waste Feedstock
NA = Not Available

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 Table 4.2-3. 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.

The vitrified product melt temperature for air blown segment of 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 4.2-3
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	-

Table 4.2-4
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

Table 4.2-4 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. The NO_x, SO_2 and CO levels during the test while operating on coal were 264, 107, and 515 ppmv (corrected to 3% O_2, dry gas), 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.

Test No. 42

Test Run 42 evaluated the vitrification of an ash generated by the incineration of sewage sludge using a washed Upper Elkhorn coal 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. 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 combustor 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 was due primarily to 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 NO_x, SO_2 and CO levels during the test run were 264, 107, and 515 ppmv (corrected to 3% O_2, dry gas), respectively. The total uncontrolled particulate carryover was 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 4.2-5. Table 4.2-6 shows that the majority (60%) of the particles not captured by the venturi scrubber had an aerodynamic particle size less than 5.0 µm.

Table 4.2-5
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 4.2-6
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

The glass product appeared fully vitrified and homogeneous. The quantitative chemical analysis of the vitrified product is shown in Table 4.2-7. The TCLP test data is shown in Table 4.2-8 and indicate that the vitrified product readily passes the leaching test requirements for RCRA metals.

Test No. 45

Test No. 45 evaluated injecting coal, co-axially with the batch, directly into the CRV combustor. 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 combustor 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 4.2-9.

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 total heat rate of 3.5 million Btu/ton. Table 4.2-10 give the chemical compositions for the feedstock and the vitrified product. The glass color was a light green with streaks 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 combustor 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 combustor 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 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.

Table 4.2-7
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 4.2-8
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

Table 4.2-9
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 4.2-10
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	-

During the period of oxygen enrichment, the NO_x, SO_2 and CO levels were 200, 130, and 80 ppmv (corrected to 3% O_2, dry gas), 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 4.2-11 shows that the majority (71%) of the particles not captured by the venturi scrubber had an aerodynamic particle size less than 50 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 4.2-12.

Table 4.2-11
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 4.2-12
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

4.2.2 Proof-of-Concept System Tests

The preliminary system tests established reliable operation of the primary components of the CMS™ process and identified the need for a flue gas cleanup system with high efficiency removal of particulate down to submicron size range. Following the preliminary tests, thirteen proof-of-concept tests were performed to prove the commercial viability of the CMS™ concept for vitrification of specific industrial wastes, including spent potliner from the aluminum reduction industry, ash from industrial coal-fired boilers, and ash from Toxic Substance Control Act (TSCA) incinerators.

An evaluation of alternative cleanup devices for the CMS™ test facility was also performed considering a baghouse, dry electrostatic precipitator (DESP), and wet electrostatic precipitator (WESP). A WESP was selected as the most appropriate alternative for flue gas cleanup at the CMS™ test facility based on its high particulate removal efficiency over a wide range of flue gas composition and conditions. The physical characteristics of the particulate carryover from the vitrification of many waste materials were found in the preliminary testing to be such that at the temperatures required for removal in a baghouse, the particulates are sticky, tend to agglomerate, and may result in blinding of the bags. The particulate removal efficiency of a DESP is strongly dependent on the composition of the flue gas. Because of the diverse potential applications of the CMS™, the types of feedstock processed in the CMS™ test facility and thus the flue gas compositions are expected to vary significantly. Additionally, the use of either a baghouse or DESP would require that the flue gas quench system in the facility be modified to ensure that the flue gas entering these cleanup devices did not contain significant quantities of liquid droplets. A WESP uses an electrostatic charge to remove water droplets from the flue gas which take with them the particulates. A WESP is very efficient in collecting particulates down to the submicron size range if particulate passing through the WESP is uniformly coated with water. The WESP selected for installation in the CMS™ test facility was designed to ensure this characteristic, as described in further detail in Section 4.1. The WESP was installed in the facility prior to Test 55.

4.2.2.1 Test 50

The first proof-of-concept test was performed using industrial boiler flyash supplied by Hoechst Celanese Corporation as the feedstock. Hoechst Celanese currently operates a large number of coal-fired boilers which produce approximately 200 tons per day of flyash. The purpose of the test was to evaluate the feasibility of using a coal-fired CMS™ to produce a salable glass product from their flyash, particularly asphalt shingle granules. For this test, a second waste feedstock consisting of 98% Iron was added in small quantities to turn the glass completely black so that it would pass the opacity specification for shingle granules. The black color characteristic of the granules is important to prevent ultraviolet light transmission which would have a deteriorating effect on the shingle asphalt. Initially during the test, temperatures in the cyclone melter were very high (>2700°F). This indicated that the carbon char in the ash was not completely combusting in the CRV combustor and that final char burnout was occurring in the melter. Additionally, there was some magnetic metal found intermixed with the glass product indicating that reducing conditions existed in the CMS™. Oxygen was then introduced into the CRV combustor to improve the combustion of the char particles. The improved combustion was indicated by a temperature rise in the CRV combustor and a stabilization of the temperature in the cyclone melter.

Product from this test was sized and sent to an asphalt shingle manufacturer for evaluation. The glass product from this test satisfied the quality control requirements for color. The results of the evaluation indicated that the material satisfied the opacity criteria. Granules made from vitrified product that was rapidly water quench were too friable relative to specifications; however, product that was air quenched more slowly passed the friability criteria.

4.2.2.2 Tests 55, 62, 68, 69, 70, and 77

These six tests were performed with the objective of determining the feasibility of vitrifying spent aluminum potliner (SPL) in the Vortec CMS™ to produce a safe, recyclable glass product. The SPL feedstock consists of an anthracite coal cathode 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 or casual water. The first test (Test 55) was conducted using a surrogate for the waste containing 10% anthracite coal by weight (the actual waste contains 30% anthracite). The other five tests were conducted using actual SPL generated by Ormet Corporation at their Hannibal, Ohio, aluminum reduction plant. Ormet Corporation funded a major portion of the vitrification trials and effluent analysis.

Test 55

Test 55, using an anthracite coal and a surrogate industrial waste as the feedstock, was conducted with oxygen enrichment to ensure complete combustion of the anthracite. The feedstock melted at a very high temperature (approximately 2900°F). Preliminary evaluation of the glass produced indicated that most of the carbon was combusted prior to the melting of the glass. The glass had a low carbon content and was light green in color. The light green color indicated that the glass was fully oxidized. If any carbon had been remaining when the glass was molten, the glass would have been reduced and black in color. This test was funded by the generator of the industrial waste.

Test 62

Based on the encouraging results of the surrogate industrial waste, a second test (Test 62) was funded by the industrial waste generator using the actual waste as the feedstock. The objective of this test was to verify that actual spent aluminum potliner (SPL) could be vitrified in the CMS™ producing a non-leachable glass product.

Approximately 1000 kg of SPL was delivered, pre-crushed to nominally minus 1/2 inch, to the pilot-plant test facility located in Harmarville, PA. This material was further crushed and screened to minus 40 mesh using Vortec's vibrating ball mill. This material was weighed and 250 kg was set aside for this test. The chemical composition of the SPL used for this test is provided in Table 4.2-13.

Based on the results of Test 55 with the surrogate waste, the batch formulation for the first treatability test (Test 62) was modified to include a small amount of glass cullet to improve the melting characteristics of the SPL. Additional additives included silica sand and limestone.

The additives and SPL were loaded into the batch tank and were air-blended in the batch tank. 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 combustor. The oxygen allows for more rapid combustion of the large amount of

Table 4.2-13
SPL Chemical Composition

Determination	Pulverized SPL (Wt. %)
Na_2O	23.8
Al_2O_3	22.8
CaO	2.57
Fe_2O_3	2.02
SiO_2	16.5
SO_3	0.27
C	23.8
F	13.2

carbon in the SPL prior to the melting of the inorganic constituents. A commercial SPL process unit was 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 combustor. The feedstock was rapidly heated in the flame zone and the carbonaceous materials are rapidly volatilized and incinerated and the metal contaminates are oxidized. The inert materials were heated to nominally 2700°F.

The preheated solid materials from the CRV combustor enter the cyclone melter where they are separated to the chamber walls to form a molten glass layer. The glass produced and the exhaust products exit the cyclone melter through a tangential exit channel and enter a glass separation chamber where the molten vitrified product is drained and the flue gases exit the system.

For this test, the feedstock was pneumatically transported and axially injected into the top of the CRV combustor using the existing dense phase pneumatic convey system at our test facility.

Prior to this test, the system had been idling with refractory temperatures maintained at approximately 2700°F. Because of the high anthracite content of the SPL, the systems natural gas thermal input to the CRV combustor was ramped down to approximately 1.5 MM Btu/hr and the SPL batch feed was initiated. The SPL was initially fed to the system at a low rate to evaluate its melting characteristics. The feed rate was then ramped up to approximately 300 lbs/hr. After the batch feed had stabilized the feed rate increased to approximately 500 lbs/hr and remained relatively constant throughout the remainder of the test.

Before the batch feed had begun, oxygen flow was initiated at approximately 250 lbs/hr. This flow rate was selected based on the pilot-scale surrogate test previously conducted. Oxygen flow was maintained throughout the test to assist in the complete combustion of the carbon.

Glass product 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.

From a qualitative standpoint, the glass produced from the SPL was green in color which generally indicates that the glass is fully oxidized. Some of the green coloring may also be caused by the chrome in the system's refractory. 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 9.6% fluoride. Therefore, only about 18% of the total fluoride in the SPL was captured in the glass. During the surrogate testing, the fluoride capture rate was only 2%. This suggests that the form of the fluoride compounds in the actual SPL are more readily incorporated into the glass matrix.

The glass chemistry also indicated that a substantial quantity of sodium was also volatilized during melting. Only approximately 50% of the total available sodium in the batch was captured in the glass. This is caused by the relatively high temperatures (about 2700°F) of the CMS™ during the test. To reduce the amount of sodium carryover, the next test was run at a lower temperature with the molten glass remaining flowable. Past experience indicated that sodium volatilization can be greatly reduced if the temperatures remain below 2500°F.

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.

Two samples of glass cullet were sent to Blue Marsh Laboratory for TCLP Testing. The results of this testing in provided in Table 4.2-14. As can be seen in the table, the TCLP extract from Sample 1 contained no detectable quantities of RCRA metals, cyanide, or fluoride except for a small concentration of chromium. The chromium detected is most likely the result of the chrome refractory liner installed in the CMS™. However, the concentration of chrome is still two orders of magnitude below the TCLP regulatory limit.

The Sample 2 extract also contained no detectable concentrations except for barium. The barium concentration was also several orders of magnitude lower than the regulatory limit.

Two glass samples were sent to CELS for petrographic analysis by transmitted light microscopy. The purpose of this testing is to determine if any unmelted batch components (stones) were in the glass product. Sample 1 was glass cullet collected from the cullet cart. The cullet contained the following inclusion (stone) varieties: Cr_2O_3 stones, "opaques" with secondary Cr_2O_3 at peripheries, and primary and secondary ZrO_2 stones.

The second sample was a solid piece of glass which was thin sectioned to facilitate the analysis. The stones in this sample were essentially the same as in the first sample with the exception of an occasional small silica batch stone and one 1.5 mm metallic sphere. The metallic sphere was contamination from a previous test run which processed wastes containing a large amount of iron. The silica stones are the result of the limited glass residence time. During the test, the glass was drained from the system immediately after exiting the cyclone melter. In a commercial system, the glass would pass through a small reservoir to ensure complete dissolution of the silica. The glass produced readily passes TCLP requirements. Additional silica dissolution will only lead to the production of a more stable glass.

Some of the stones detected are from the CMS™ refractory liner. Because of the thermal cycling of the test system, the refractory liner develops small cracks which allows small pieces to spall off into the molten glass. The zirconia stones are from the refractory mortar

Table 4.2-14
Test 62 Product Glass TCLP Results

Parameter	62-1 06-3548	62-2 06-3549	P.Q.L.	RCRA/TCLP Limit	EPA Method Used
MISC. on TOTAL: (mg/kg)					
pH (Corrosivity)	5.39	5.11	+/-0.01	2-12.5	9045
METALS on TCLP Extract:	(mg/l)				
Arsenic	ND	ND	0.1	5.0	6010
Barium	ND	0.21	0.05	100.	6010
Cadmium	ND	ND	0.02	1.0	6010
Chromium	0.06	ND	0.02	5.0	6010
Lead	ND	ND	0.1	5.0	6010
Mercury	ND	ND	0.002	0.2	7470
Selenium	ND	ND	0.05	1.0	6010
Silver	ND	ND	0.02	5.0	6010
MISC on TCLP Extract:	(mg/l)				
Cyanide	ND	ND	0.01	---	335.2
Fluorene	ND	ND	0.001	---	625

ND = The compound indicated was not detected at or above the practical quantitation limit (PQL) listed for the method performed.

in the separator/reservoir. The commercial SPL processing system is specifically designed to minimize refractory wear. The commercial system also will not be thermally cycled which will eliminate refractory spalling.

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 the test, the SPL generator funded additional testing.

Test 68, 69, 70 and 77

Based on the results of Test 62, the SPL generator elected to fund four additional tests to collect data for a petition to delist the glass product.

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 4.2-15.

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 these tests, oxygen was also introduced co-axially with the feedstock into the top of the CRV combustor. 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 is 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 combustor. The feedstock is rapidly heated in the flame zone and the carbonaceous materials are rapidly volatilized and incinerated and the metal contaminants are oxidized.

The three tests were performed back to back. 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, the system thermal input to the CRV combustor 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.

Table 4.2-15
SPL Chemical Composition

Determination	Pulverized SPL (Wt. %)
Na_2O	23.8
Al_2O_3	22.8
CaO	2.57
Fe_2O_3	2.02
SiO_2	16.5
SO_3	0.27
C	23.8
F	13.2

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 combustor 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.

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 were 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 are provided in Table 4.2-16. 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 WESP.

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 Test 68, an additional sampling location was included after the WESP.

Approximately 864 ppm of fluoride was detected on the inlet side of the WESP for Test 68, and 2.6 ppm after the WESP. For Test 70, about 720 ppm of fluoride was measured before the WESP. 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.

Table 4.2-16
Test 69 Product Glass TCLP Results

	Test 69 (w/O_2)	Test 69 (wo/O_2)	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	-

The flue gas particulates were isokinetically sampled. The data indicates a particulate emission rate for Test 68 of approximately 23.35 lbs/hr before the WESP, and 0.24 lbs/hr after. The sampling performed during Test 70 resulted in a particulate emission rate of about 27.99 lbs/hr before the WESP. Detailed analysis of the CSC data indicates that the measured flue gas flow rates before the WESP 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 Tests 68 and 70, respectively. Approximately 5.75 lbs/hr of particulate were also captured for Test 68 in the spray quench water giving a total particulate emission rate of 19 lb/hr. During Test 70, 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 tests were 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.

Test 77

The purpose of Test 77 was to evaluate the effectiveness of the CMS™ in vitrifying SPL at higher feed rates and provide additional glass property data for the delisting petition.

As during the previous tests, the SPL was crushed and screened to minus 40 mesh using Vortec's vibrating ball mill. 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.

Prior to the test, the system had been idling with refractory temperatures maintained at approximately 2700°F. The feedstock was introduced along the longitudinal centerline of the CRV. The feedstock was rapidly heated in the flame zone and the carbonaceous materials were rapidly volatilized and the metal contaminants were oxidized.

During the course of the test, 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. A separate particulate capture was also performed and the particulate was sent out for analysis.

Samples of the glass cullet for each of the tests were 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 the test was also conducted by Blue Marsh Laboratories.

No major operational problems were encountered during the test.

4.2.2.3 Tests 75, 76, and 78

An additional task was added by the PETC/Phase III program for the pilot-scale melt testing of simulated Toxic Substance Control Act (TSCA) incinerator ash. The objective of this testing was to demonstrate the ability of the Vortec Combustion and Melting System to remediate ash from DOE operated TSCA waste incinerators processing solid materials with low-level radioactive constituents. Under the task, a surrogate TSCA incinerator ash was defined based on discussions with DOE and Martin Marietta personnel at Oak Ridge National Laboratory. Laboratory melt tests were then performed to determine the need for additional glass forming agents to meet the operating temperature specifications of Vortec's CMS™ process and specifications for a stable, durable glass product. This was followed by pilot-scale testing to assess the technical feasibility of vitrifying TSCA incinerator ash in the CMS™ to produce a stable, durable glass product immobilizing heavy metal and radionuclide contaminants. Approximately 10,000 lbs of surrogate TSCA ash were vitrified during pilot-scale testing. Samples of the vitrified product were collected throughout the testing and analyzed by the Toxicity Characteristic Leaching Procedure (TCLP) and the Product Consistency Testing (PCT) procedures. All the samples passed the TCLP test for leachability of the metal contaminants and the PCT test for chemical durability of the vitrified product. The current PCT specification for nuclear waste glasses is a weight loss of 1g/m2/day for Li, Na, K, Si, and B combined. The PCT result for the vitrified product was approximately 0.003 g/m2/day for Li, Na, K, Si, and B combined. Therefore, it is concluded that the CMS™ can successfully process surrogate TSCA ash, resulting in a fully-reacted vitrified product without the need for additional glass forming agents.

Test 75 and 76

The pilot-scale testing was composed of two demonstration tests. The primary purpose of the first test (Test 75) in the sequence was to evaluate the melting performance and to define the expected range of flue gas emissions from the Vortec CMS™ when processing a surrogate TSCA incinerator ash containing approximately 5 wt% carbon.

A second demonstration test (Test 76) was performed with a surrogate TSCA incinerator ash containing 12 wt% carbon. The goal of the second test was to obtain additional data on the performance of the CMS™ when processing simulated TSCA ash and to evaluate the effect of the relatively high carbon content in the ash on the capture rate of the heavy metal and radionuclide surrogates in the vitrified product.

A combination of municipal solid waste incinerator (MSWI) bottom ash and flyash was used as the base material for the surrogate TSCA ash. Heavy metal oxides, simulated radionuclides, and pulverized coal were added to the ash to increase the concentrations of the heavy metals, simulated radionuclides, and carbon to levels recommended by DOE based on discussions with DOE and Martin Marietta personnel at Oak Ridge National Laboratory. Arsenic, barium, cadmium, chromium, and lead were added to the ash mixture as metal oxides. Cerium and cesium were added to the ash mixture as simulated radionuclides. Simulated radionuclides are non-radioactive metals, the behavior of which will simulate the behavior of the true radionuclide species in the CMS™. Cerium was added as cerium oxide to simulate the behavior of uranium within the CMS™, for its chemical properties are similar to those of uranium. Cesium was added as cesium chloride, as specified by DOE, to simulate the behavior of radioactive cesium within the CMS™. Mercury, selenium, and silver were excluded due to their high cost or because Vortec presently considers these materials to be too hazardous to handle at our pilot facility. However, the metals which were added to the surrogate ash represent both semi-volatile and non-volatile metals; therefore, the behavior of the excluded metals can be estimated based on the behavior of the metals included in the surrogate ash. The surrogate TSCA incinerator ash formulation is shown in Table 4.2-17.

The carbon content of the surrogate TSCA ash varied between the two tests to study its effect on the capture rate of the heavy metal and radionuclide surrogates in the vitrified product. The carbon content of the surrogate ashes used in the feasibility tests were 5 wt% and 12 wt%. In order to vary the carbon content of the ash mixture, appropriate quantities of pulverized coal were added to the surrogate ash mixture. The chemical composition of the coal used as an additive in the feasibility testing is listed in Table 4.2-18.

The batch tank was loaded with the appropriate surrogate ash and coal feedstock, and the feedstock was pneumatically blended. Laboratory scale testing showed that glass forming additives were not necessary to meet the specifications of the CMS™. The resulting chemical composition of the blended feedstocks is presented in Table 4.2-19.

Prior to the initiation of either of the feasibility tests, the system was brought to a temperature of approximately 2500°F. Test 75 was conducted using the 5% carbon feedstock. The test was initially conducted using a molten glass temperature of 2500°F at a feed rate of 1000 lbs/hr (Test 75a). Later the test conditions were changed (Test 75b) by

Table 4.2-17
TSCA Feedstock Formulations and the Resulting Metals Concentration

	Test 75 lbs	Test 76 lbs
MSWI Bottom Ash	2729	2337
Fly Ash	2145	1837
Coal	193	600
As_2O_3	19.8	19.4
BaO	12.7	11.5
CdO	16.65	16.35
Cr_2O_3	18.6	18.6
PbO	1.1	2.4
CeO_2	15.0	14.7
CsCl	15.4	14.7

Element	Test 75 Concentration of Element ppm	Test 76 Concentration of Element ppm
As	2975	3082
Ba	3022	2877
Cd	2910	3019
Cr	2938	3026
Pb	2730	2757
Ce	2361	2453
Cs	2353	2382

Table 4.2-18
Chemical Composition of Coal

Proximate Analysis	dry wt%
Ash	1.23
Volatile	35.38
Fixed Carbon	63.39
Sulfur	0.61

Ultimate Analysis	wt %
Carbon	85.44
Hydrogen	5.32
Nitrogen	1.62
Chlorine	-
Sulfur	0.61
Ash	1.23
Oxygen	5.78

Ash Analysis	dry wt%
SiO_2	47.17
Al_2O_3	30.9
K_2O	1.46
Na_2O	1.32
CaO	3.46
Fe_2O_3	10.09
MgO	0.89
SO_3	1.32
BaO	0.32
TiO_2	1.89
P_2O_5	0.31
SrO	0.39
Mn_3O_4	0.06

Table 4.2-19
Chemical Composition of the Combined Feedstocks

Element	Oxide	Test 75 wt% of oxide	Test 76 wt% of oxide
Al	Al2O3	9.1466	8.6063
As	As2O3	0.3927	0.4068
Ba	BaO	0.3384	0.3222
B	B2O3	0.1226	0.1028
Cd	CdO	0.3317	0.3442
Ca	CaO	17.738	17.227
Ce	CeO2	0.2904	0.3017
Cs	CsCl	0.2981	0.3017
Cl	Cl	3.6794	3.3415
Cr	Cr2O3	0.4289	0.4417
Fe	Fe2O3	6.052	5.3874
Pb	PbO	0.2949	0.2977
Mg	MgO	4.9534	5.502
K	K2O	1.463	1.3131
Si	SiO2	33.0417	30.4023
Na	Na2O	3.463	3.1379
S	SO3	3.406	3.358
C	C	5.013	12.184
Hg	HgO	ND	ND
Se	Se	2 ppm	5 ppm
LOI		13.11	20.80

ND ≡ Not detected.

allowing the glass temperature to decrease to 2300°F to investigate the effect of temperature on the partitioning of the metal contaminants among the effluent streams.

Test 76 was conducted using the feedstock containing 12% carbon. During the initial portion of this test (Test 76a) the molten glass temperature was held at 2300°F and the feed rate was set at 500 lbs/hr. Later during the test (Test 76b), the feed rate was increased to 1000 lbs/hr and the temperature was increased to 2450°F.

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

From a qualitative standpoint, the glass produced from the surrogate TSCA ash was consistently black in color throughout both tests. Within a single glass sample, no color variations could be seen in the glass cullet. Table 4.2-20 presents the chemical composition of the glass formed during the feasibility tests. The chemical analysis was performed by CELS.

The effect of operating temperature and carbon content in the ash on the composition of the glass seems to be negligible for all the glass forming compounds and the metal contaminants, except for cadmium. The concentration of cadmium in the glass increased by a factor of two for Test 76a—the low temperature, low feed rate test.

Both glass cullet and glass patty samples, collected during both feasibility tests, were sent to Blue Marsh Laboratories for TCLP testing. The TCLP leachates were analyzed for the metal contaminants added to the surrogate TSCA ash. The results of the TCLP testing, along the concentration of the metal contaminants in the glasses, are displayed in Table 4.2-21. All the TCLP analyses indicate that all the glass produced during Vortec's feasibility testing has excellent leach resistance for the heavy metals and simulated radionuclides.

Table 4.2-20
Chemical Composition of Glass Produced during Feasibility Tests

	Test 75a	Test 75a	Test 75b	Test 75b	Test 76a	Test 76a	Test 76b	Test 76b
	Glass	Glass	Glass	Glass	Glass	Glass	Glass	Glass
	Cullet	Patty	Cullet	Patty	Cullet	Patty	Cullet	Patty
	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%
Cs_2O	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
K_2O	0.73	0.76	0.76	0.74	0.78	0.78	0.68	0.68
Na_2O	2.88	2.86	2.91	2.91	2.91	2.91	2.74	2.75
Al_2O_3	12.5	12.2	12.4	12.6	11.8	11.9	11.9	12.0
As_2O_3	0.14	0.12	0.15	0.14	0.17	0.15	0.16	0.13
B_2O_3	0.17	0.16	0.18	0.19	0.14	0.14	0.14	0.15
BaO	0.38	0.39	0.38	0.38	0.36	0.38	0.40	0.39
CaO	22.5	22.3	22.1	22.1	21.6	21.9	22.4	22.6
CdO	0.023	0.02	0.042	0.039	0.080	0.081	0.033	0.035
CeO_2	0.24	0.32	0.28	0.29	0.46	0.27	0.35	0.28
Cr_2O_3	0.48	0.47	0.47	0.47	0.44	0.45	0.52	0.51
Fe_2O_3	7.60	7.75	7.48	7.37	7.51	7.61	7.46	7.53
HgO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MgO	6.29	6.10	6.52	6.53	7.10	7.20	7.23	7.37
PbO	0.16	0.16	0.17	0.17	0.17	0.19	0.15	0.15
SiO_2	42.2	42.9	42.3	42.3	42.7	43.1	42.0	42.2
C	0.008	0.008	0.007	0.007	0.008	0.009	0.008	0.009
SO_3	0.17	0.17	0.068	0.049	0.044	0.045	0.031	0.038
Se	<1 ppm	<1 ppm	<1 ppm	<1 ppm	<1 ppm	<1 ppm	<1 ppm	<1 ppm
Cl	0.29	0.32	0.27	0.20	0.069	0.088	0.12	0.13

Table 4.2-21
Glass TCLP Results with Corresponding Metals Concentrations

	Glass Cullet Glass Composition ppm	Glass Cullet TCLP ppm	Glass Patty Glass Composition ppm	Glass Patty TCLP ppm	TCLP RCRA Limit// Practical Quantitation Limit ppm
			Test 75a		
As	1061	ND	909	ND	5.0 // 0.1
Ba	3393	0.14	3482	0.14	100. // 0.05
Cd	202	ND	175	ND	1.0 // 0.02
Cr	3288	ND	3219	ND	5.0 // 0.02
Pb	1482	0.3	1482	0.3	5.0 // 0.1
Ce	1951	0.1	2602	0.1	NA // 0.1
Cs	187	ND	283	ND	NA // 0.1
			Test 75b		
As	1136	0.4	1061	ND	5.0 // 0.1
Ba	3393	0.14	3393	0.19	100. // 0.05
Cd	368	ND	342	ND	1.0 // 0.02
Cr	3219	ND	3219	ND	5.0 // 0.02
Pb	1574	0.2	1574	0.2	5.0 // 0.1
Ce	2276	0.1	2358	0.2	NA // 0.1
Cs	187	ND	187	ND	NA // 0.1
			Test 76a		
As	1288	ND	1136	ND	5.0 // 0.1
Ba	3214	0.16	3393	0.20	100. // 0.05
Cd	702	0.02	711	0.03	1.0 // 0.02
Cr	3014	ND	3082	ND	5.0 // 0.02
Pb	1574	ND	1759	0.1	5.0 // 0.1
Ce	3740	0.1	2195	0.2	NA // 0.1
Cs	187	ND	187	ND	NA // 0.1
			Test 76b		
As	1212	ND	985	ND	5.0 // 0.1
Ba	3571	0.09	3482	0.19	100. // 0.05
Cd	290	ND	307	ND	1.0 // 0.02
Cr	3562	ND	3493	ND	5.0 // 0.02
Pb	1389	ND	1389	0.1	5.0 // 0.1
Ce	2846	0.1	2276	0.2	NA // 0.1
Cs	187	ND	187	ND	NA // 0.1

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

Both glass cullet and glass patty samples, collected during both feasibility tests, were also sent to CELS for PCT analysis. CELS performed PCT procedure B on the glasses, and analyzed the leachates for the glass forming elements (K, Na, B, Ca, Mg, and Si). The PCT testing followed all the specifications of PCT procedure A, but PFA Teflon vessels were used instead of stainless steel. CELS also reported the final pH of the leachate. The results of the PCT testing are displayed in Table 4.2-22.

The elemental mass balances performed on the heavy metal and radionuclide contaminants accounted for between 64% and 98% of the metal contaminants in the feedstock. The partitioning of the non-volatile contaminants to the vitrified product are typical of those observed in previous testing of contaminated materials — 95+% of the Ba, 90+% of the Cr, and 95+% of the Ce are all found in the vitrified product. The partitioning of the semi-volatile contaminants among the effluent streams is dependent upon the halogen (F and Cl) content of the ash, the operating temperature of the CMS™, and may also depend on the original chemical form (metallic, oxide, chloride, etc.) of the contaminants in the ash. The chloride content of the surrogate TSCA incinerator ash used in the feasibility testing was approximately 3.5 wt%. With this relatively large concentration of chloride in the ash, the semi-volatile contaminants will tend to volatilize more easily and partition to the flue gas and the particulate carryover. The partitioning of the semi-volatile contaminants to the vitrified product was approximately 10% of the Cs, 15% of the CD, 40% of the As, and 50% of the Pb. These results are consistent with previous CMS™ test results of MSWI flyash vitrification. The carryover can be recycled back into the CMS™ process to result in significantly higher levels of capture in the vitrified product. Other testing performed indicate that greater than 95% of the semi-volatiles can be incorporated into the vitrified product through recycling.

The partitioning of the semi-volatile contaminants was not significantly different for the 5% carbon and 12% carbon feedstock tests. In the surrogate TSCA incinerator ash tests, the material carryover ranged from 4.0% to 5.4% of the feed, including the chloride carryover, depending on the operating conditions. The carryover for these surrogate TSCA incinerator ash tests are approximately half that of previous MSWI flyash vitrification tests, which corresponds with a factor of 2 ratio of the Cl content in the ashes.

Table 4.2-22
PCT Results of the Glasses Produced during Feasibility Testing

	Test 75a	Test 75a	Test 75b	Test 75b	Test 76a	Test 76a	Test 76b	Test 76b
	Glass	Glass	Glass	Glass	Glass	Glass	Glass	Glass
	Cullet	Patty	Cullet	Patty	Cullet	Patty	Cullet	Patty
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
K	1.8	2.0	2.6	2.4	2.5	4.3	2.5	2.9
	1.8	2.1	2.5	2.4	2.4	4.1	2.6	2.8
Na	5.3	5.6	7.0	6.5	8.5	12.1	7.3	8.0
	5.3	5.8	6.8	6.4	8.4	11.8	7.5	8.0
B	0.13	0.12	0.14	0.14	0.15	0.20	0.14	0.17
	0.12	0.12	0.13	0.13	0.15	0.19	0.14	0.16
Ca	17.3	17.1	20.6	20.4	22.3	16.4	22.7	23.8
	17.7	17.6	20.1	20.7	22.3	16.2	23.2	23.9
Mg	0.007	0.006	0.004	0.004	0.004	0.010	0.004	0.004
	0.005	0.005	0.004	0.003	0.003	0.007	0.003	0.002
Si	14.5	15.1	16.3	16.4	16.3	16.3	17.1	16.8
	14.3	15.0	16.2	16.6	16.6	16.3	16.8	16.9
pH	10.7	10.8	10.9	11.0	11.1	11.0	11.0	11.1
	10.7	10.8	11.0	11.0	11.1	11.0	11.0	11.1

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

Examination of the results of these tests identified the questions which should be answered through additional testing. The effect of the chloride content in the surrogate TSCA incinerator ash on the carryover and partitioning of the surrogate heavy metals and radionuclides should be quantified by processing several surrogate TSCA incinerator ashes which differ only by their chloride content. The surrogate ash formulation should then be standardized by DOE to allow any comparisons and/or conclusions of competing technologies to be drawn with non-bias data. Optimization testing could also be performed to determine the optimal ranges of operating temperatures and feed rates. The operating temperatures used in the feasibility testing were higher than required for effective operation of the CMS™. Experience has shown that molten flyash has a steep viscosity curve. Due to lack of experience with the surrogate TSCA incinerator ash, higher system temperatures (approximately 100-200°F higher than required) were used throughout the feasibility testing to ensure proper operation with concern for plugging.

Test 78

During the surrogate TSCA incinerator ash pilot-scale tests, pulsations in the batch feed system were observed. Therefore, a two-day test (Test 78) was performed to determine the cause of these pulsations. Two different batch feedstocks were used during this test: flyash and cullet. A variety of possible sources of the batch feed pulsations were explored. The cause of the pulsations was traced to a worn part in the feeder located at the bottom of the batch feed tank. The initial clearance between the rotor and the housing was 7 mm. Upon inspection, it was noted that the rotor had worn such that the housing clearance had increased to 21 mm. The problem was corrected by replacing the worn part with the corresponding part on the existing coal feed tank. No pulsations were observed during the next pilot-scale test. A new feeder (including end plates, housing and rotor) for the existing coal tank, which had previously been ordered, was procured and installed.

4.2.2.4 Tests 84, 91, and 92

These three tests were pre-tests for the 100 hour final demonstration test to verify acceptable operation of the new coal feed system installed for the demonstration test, the ability of the batch feed system to satisfactorily deliver the flyash obtained from PENELEC for the demonstration test to the CMS™, and CMS™ operating conditions for melting the flyash.

Test 84

The primary objective of Test 84 was to verify satisfactory performance of the feedstock delivery system in transporting the PENELEC flyash/additive mixture to be used in the demonstration test. The test also afforded the opportunity to conduct glass fiberizing tests with the vitrified product using the fiberizer obtained for a waste glass recycling test previously performed under a Pennsylvania Ben Franklin Fund program (Test 80). Approximately 4,000 lbs of a mixture of 60 wt% PENELEC flyash and 40 wt% dolomite was blended in the pilot-scale test facility feed tank. The CMS™ was brought to an operating temperature of 2600°F, the temperature identified via laboratory melts for effective operation of the CMS™. After a heat up period of approximately 24 hours, with natural gas as the fuel, flow of feedstock was initiated to the CMS™. The feedstock flow was slowly increased to a design run point of approximately 1,000 lbs/hr while increasing fuel and oxidant to maintain a glass temperature of approximately 2600°F. The 4,000 lbs of feedstock was vitrified in the CMS™ over a period of approximately 4 hours with no problems occurring in the feed system.

A single wheel mineral wool fiberizer provided by MFI Technologies, Inc. was installed on rails in Vortec's test facility. Although the fiberizer was originally designed for a glass throughput approximately five times that of the pilot-scale CMS™, MFI felt that it would be suitable for establishing the feasibility of producing fibers from the flyash. Modifications to the existing test facility to incorporate the fiberizer included installation of the fiberizing assembly, feed trough, and shroud/collection chamber, and modifications to the separator/reservoir tap hole to ensure a constant glass flow.

Stripping air was supplied to the fiberizer by two rented Ingersoll-Rand air compressors. One of the two compressors supplied 1600 CFM of air at 120 psig while a smaller compressor supplied 825 CFM at 120 psig. The air from both of the compressors is combined at a manifold and a single 3 inch diameter high pressure air line is connected to the air stripping ring. This system provides a minimum air flow of 2400 CFM at 100 psig to the air ring.

Glass flow control from the separator to the fiberizer feed trough was provided by a simple weir inside the separator/ reservoir and a 1.5 inch diameter refractory tube. The end of the tube is angled to provide a constant even glass flow.

The feed trough is fabricated from carbon steel and is lined with graphite to prevent the molten glass from sticking to the trough. However, the addition of a very small spray of water is required at the point where the glass stream first contacts the trough to keep the glass from sticking at that point. The end of the trough is curved to provide the proper glass contact angle at the fiberizer.

Fibers were successfully produced from the vitrified flyash over short durations. Because of the large size and associated heat loss of the spinning wheel relative to that required for the flow of glass from the pilot-scale CMS™, a continuous flow of glass over the wheel could not be maintained for more than several seconds. This resulted in several seconds production of fibers followed by separation of the glass from the surface of the wheel in small "chunks." The diameter of the fibers had the appearance of being larger than conventional mineral wool. This is attributed to the high viscosity of the glass leaving the spinner, as evidenced by the difficulty in getting the glass to flow over the wheel. Although the viscosity of the glass entering the spinner appeared low, glass produced from ash typically has a steep viscosity, and because of the oversized spinner, the rapid cooling of the glass across the wheel surface resulted in a significant increase in viscosity. Analysis of the glass chemistry and performance of the pilot scale trials suggest that, with a suitably matched fiberizer, it is projected that commercial quality mineral wool can be manufactured with the CMS™ process using boiler flyash as the feedstock.

Tests 91 and 92

Tests 91 and 92 were conducted on the same day in series to check out the operation of the newly installed coal feed system. Approximately 1,200 lbs of PENELEC flyash and dolomite mixture was prepared in the test facility's feed tank. Approximately 2,000 lbs of pulverized coal was loaded into the coal feed tank. A total of approximately 9 hours of coal fired operation was performed, approximately 3 hours of feedstock melting followed by 6 hours of coal-fired operation with no feedstock flow. Some problems were encountered in the control logic of the coal feed system during the first three hours of operation. NOL-TEC, the feed system supplier, corrected the control logic, and the system was then operated at design conditions with no other problems encountered. The performance of the system during the pilot scale trials indicated the new system was an acceptable alternative pneumatic transport system design.

4.2.3 Demonstration Test - Test 93

The primary objective of this final test of the program was to demonstrate the continuous operation of the CMS™ under normal user load. The ability of the CMS™ to demonstrate continuous trouble-free operation (equipment durability) and to produce a fully-reacted vitrified product with a consistent composition were the measures of success.

A secondary objective of the test was to document refractory wear within the CMS™ while processing a coal-fired boiler flyash. The CRV combustor and cyclone melter components were completely relined prior to the test. Three different refractories were employed: a bonded AZS refractory from North American, a low-cement AZS castable from Zedmark, and a low-cement AZS castable from Corhart. The cyclone melter was lined with the bonded AZS refractory, backed by 2 inches of insulating refractory. The cylindrical portion of the CRV combustor was relined with the low-cement AZS from Corhart, and the cone portion of the CRV combustor with the Zedmark material. These refractories were installed in direct contact with the water-cooled shell. Therefore, a comparison of refractory wear could be made between the insulated refractory and the actively water-cooled refractory. Low cement castables do not typically perform as well as bonded refractories, but because of the active cooling, wear rates similar to or better than past experiences with the bonded refractory were expected.

The majority of refractory wear data obtained to date had been with a bonded AZS refractory which had been installed with an insulating backup material. It should be noted, however, that the refractories used in the pilot scale test loop have not been the optimum refractories for use with the feedstocks utilized in all the testing to date. The refractories selected were chosen for fast start-up and shutdown in order to minimize the time duration of the test periods.

The demonstration test consisted of one test run, with a duration of 105 hours, approximately one-half (46 hours) performed with coal as the primary fuel source, the other half with natural gas. The test was conducted over a five day period from September 11 to September 16, 1994. Approximately 50 hours of melting operation were performed vitrifying approximately 25 tons of a coal-fired utility boiler flyash/dolomite mixture, producing a fully-reacted vitrified product. The flyash, supplied by PENELEC, contained approximately 4% by weight of carbon. The flyash/dolomite mixture (60%/40% by weight) provided approximately 10% of the total energy input to the vitrification system. No problems were encountered in the operation of the CMS™ components during the demonstration test. The system operated continuously except for periodic shutdowns to perform cleanout maintenance on the flue gas quench assembly. Chemical composition and Differential Thermal Analysis (DTA) conducted on samples of the vitrified product indicate that the chemical composition of the product was consistent throughout the test.

4.2.3.1 Test System Description

The test system was located in a High Bay Area, with plan dimensions of 40' x 100', and a height of 64 ft., at the University of Pittsburgh Applied Research Center in Harmarville, PA. This area includes a tower for support of test equipment, and a 5-ton bridge crane.

The test system configuration was that described as Test Loop 3C in Section 4.1. The system included a CRV combustor, cyclone glass melter, glass/gas separator-reservoir, flue gas quench assembly, wet electrostatic precipitator, and cullet (vitrified product) quench assembly. A dense-phase pneumatic feed system delivered pulverized feedstock to the CMS™, and a dilute-phase pneumatic coal feed system delivered pulverized coal to the CMS™. Combustion air was preheated via an indirect-fired air heater. A flue gas instrumentation system, containing four Rosemount Analytical/Beckman analyzers, provided on-line continuous measurement of CO, O_2, SO_2, and NO/NO_x. In addition, the system has Method 5 instrumentation for the measurement of particulate emissions. A Genesis computer package is used for the data logging of all thermocouple, pressure, and flow measurements made in the course of a typical test run.

4.2.3.2 Feedstock/Coal Preparation

The feedstock for the demonstration test was a mixture of a coal-fired boiler flyash, supplied by PENELEC from their Homer City, PA plant, and dolomite. Laboratory melt tests demonstrated that the melt (liquidous) temperature of the flyash was in excess of 3000°F. The addition of dolomite to the ash to achieve a 60% flyash/40% dolomite mixture lowered the melt temperature to an acceptable range (approximately 2600°F-2700°F). This mixture would also result in a glass composition similar to that of a commercial mineral wool.

Throughout the test, a combination of three Pittsburgh seam coals was used. The proximate and ultimate analyses and ash analyses for the coals are shown in Tables 4.2-23 through 4.2-25. Due to the long duration of the test, the three different Pittsburgh seam coals were mixed to generate a sufficient quantity of a single coal with a uniform composition.

4.2.3.3 Test Parameters and Data

Figure 4.2-1 is a process schematic of the Vortec test facility at U-PARC. Included, with numerical designators, are the locations of the instruments used to control and assess the

Table 4.2-23. Chemical Composition of Coal 1

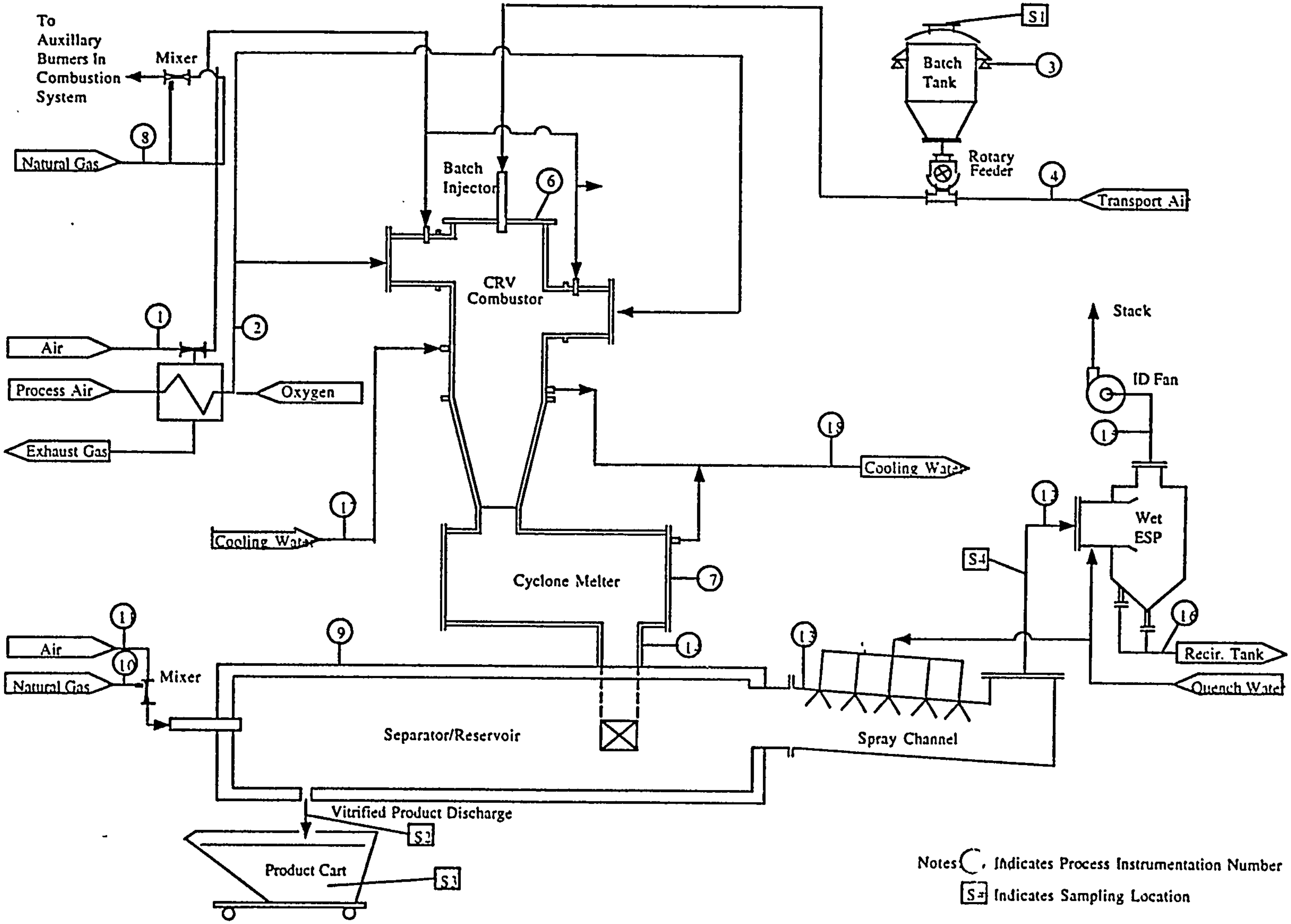
Proximate Analysis	as rec'd wt%	Ash Analysis	dry wt%
Moisture	2.67		
Ash	8.17	SiO_2	45.22
Volatile	37.00	Al_2O_3	23.46
Fixed Carbon	52.16	K_2O	1.45
Sulfur	2.15	Na_2O	0.49
		CaO	2.67
Ultimate Analysis	as rec'd wt %	Fe_2O_3	20.51
Carbon	73.22	MgO	0.51
Hydrogen	4.54	SO_3	2.62
Nitrogen	1.41	BaO	0.11
Chlorine	-	TiO_2	1.01
Sulfur	2.15	P_2O_5	0.60
Ash	8.17	SrO	0.12
Oxygen	7.84	Mn_3O_4	0.08

Table 4.2-24. Chemical Composition of Coal 2

Proximate Analysis	as rec'd wt%	Ash Analysis	dry wt%
Moisture	3.83		
Ash	7.97	SiO_2	47.66
Volatile	36.02	Al_2O_3	24.74
Fixed Carbon	52.18	K_2O	1.44
Sulfur	1.89	Na_2O	0.34
		CaO	1.74
Ultimate Analysis	as rec'd wt %	Fe_2O_3	19.06
Carbon	72.76	MgO	0.46
Hydrogen	4.52	SO_3	0.96
Nitrogen	1.45	BaO	0.12
Chlorine	-	TiO_2	1.05
Sulfur	1.89	P_2O_5	0.72
Ash	7.97	SrO	0.13
Oxygen	7.58	Mn_3O_4	0.08

Table 4.2-25. Chemical Composition of Coal 3

Proximate Analysis	as rec'd wt%	Ash Analysis	dry wt%
Moisture	2.44		
Ash	8.38	SiO_2	46.23
Volatile	37.14	Al_2O_3	23.82
Fixed Carbon	52.04	K_2O	1.64
Sulfur	2.17	Na_2O	0.48
		CaO	2.45
Ultimate Analysis	as rec'd wt %	Fe_2O_3	19.75
Carbon	73.51	MgO	0.53
Hydrogen	4.67	SO_3	2.02
Nitrogen	1.42	BaO	0.00
Chlorine	-	TiO_2	1.11
Sulfur	2.17	P_2O_5	0.60
Ash	8.38	SrO	0.13
Oxygen	7.41	Mn_3O_4	0.07



Notes ◯, Indicates Process Instrumentation Number
S# Indicates Sampling Location

Figure 4.2-1 Schematic of Vortec Test Facility thermodynamic performance of the system. Table 4.2-26 presents the instrumentation type and its system location. The sampling point locations are indicated on Figure 4.2-1 with the designators S1, S2, S3, S4 and S5. These locations were selected because they are truly representative of the process inlet and exit state points and will represent the true potential of the system to physically alter the feedstock. Selection of sampling points elsewhere in the system would not be representative of the process's performance.

4.2.3.4 Instrument Monitoring, Data Acquisition, and Control System

The Vortec test facility is extensively instrumented. The facility uses a PC-based computer system to simultaneously operate the system, monitor the system's performance, and record time histories of selected system parameters. Four types of measurement time histories are made; namely: pressures, temperatures, weights, and flows. In addition, the concentrations of O_2, CO, NO_x and SO_x in the flue gas are recorded.

The supervisory control and data acquisition (SCADA) system's architecture is based on the following components.

1. Measuring Element
2. Measurement Transmitter/Transducer
3. Analog to Digital (or D/A) Interface Hardware
4. Computer Monitor

The control system and data logging system is an IBM-486 computer which is dedicated to operating a Genesis control series program. The computer communicates with the subsystems through digital and analog input/output and data highway communications cards.

The Genesis control series program uses drivers to facilitate communications between the computer and the input/output hardware connections. Using available data, Genesis runs a developed control strategy designed to provide the following functions: data acquisition, recording, trending, mathematical, logical, indication, status, digital control, analog control, alarming, sequencing, timing, reporting, and user intervention.

Table 4.2-26. Test Facility Instrumentation

Process Instrumentation

NOTE: Work with Figure 4.2-1.

System	Station No.	Sub-system/ Component	Measurement	Instrument	Location	Recorded by
Process Air Supply and Preheat Air	1	Lamson Blower	Pressure Temperature Flow	Pressure Transmitter Pressure Gauge K thermocouple Dial thermometer Orifice plate	Blower outlet Blower outlet Blower outlet	Data Logger Reference only Data Logger Reference only Data Logger
	2	Air Heater	Temperature	K thermocouple	Heater outlet	Data Logger
Batch Supply/Feed	3	Batch Tank	Weight Coal Flow	Load cells Load cells	Tank supports Tank supports	Data Logger Manual - loss in weight calc.
	4	Transport Air	Pressure Temperature Flow	Pressure transmitter K thermocouple Orifice plate	Air supply line Air supply line Air supply line	Data Logger Data Logger Data Logger
CMS™	6	CRV	Gas Temperature Gas Pressure Refractory Temperature	S Thermocouple S Thermocouple Pressure transmitter S Thermocouples	Inlet arm CRV outlet Viewport Embedded in refractory at CRV outlet	Data Logger Data Logger Data Logger Data Logger
	7	Cyclone Melter	Gas Temperature Gas Pressure	S Thermocouple Pressure transmitter	Cyclone melter endwall Viewport	Data Logger Data Logger
	8	Natural Gas	Pressure Temperature Flow	Pressure transmitter K thermocouple Orifice plate	Process gas supply line Process gas supply line Process gas supply line	Data Logger Data Logger Data Logger
Conditioning	9	Separator/Reservoir	Gas Temperature Refractory Temperature Gas Pressure	S Thermocouple S Thermocouple Pressure transmitter	Inlet Embedded in refractory Viewport	Data Logger Data Logger Data Logger
	10	Natural Gas	Pressure Temperature Flow	Pressure transmitter K thermocouple Orifice plate	Burner gas supply line Burner gas supply line Burner gas supply line	Data Logger Data Logger Data Logger
	11	Combustion air	Pressure Temperature Flow	Pressure transmitter K thermocouple Orifice plate	Eclipse blower outlet Eclipse blower outlet Eclipse blower outlet	Data Logger Data Logger Data Logger
Flue Gas/Quench	12	Stack	Flue gas temperature	K Thermocouple Dial thermometer	Spray channel outlet Spray channel outlet	Data logger Reference
	13	Spray Channel	Flue gas temperature	S Thermocouple	Spray Channel Inlet	Data Logger
	14	CMS™ Outlet	Excess oxygen CO NO/NOx SOx	Beckmann Model 755 Oxygen AnalyzerBeckmann Model 870 Non-Dispersive Infrared Analyzer Beckman Model 951A NO/NOx Analyzer Beckman Model 880 Non-Dispersive Infrared Analyzer	Spray Channel Inlet Spray Channel Inlet Spray Channel Inlet Spray Channel Inlet	Data Logger Data Logger Data Logger Data Logger
	15	Stack	Particulate	Anderson Analyzer	Stack	not in use
	16	Spray Channel	Particulate	Grab Sample	Spray Channel Drain	Manual
Cooling Water	17	Global view	Supply Temperature	K Thermocouple Dial Thermometer	Supply water header Supply water header	Data Logger Manual
	18	Global View	Ave. return temperature	K Thermocouple	Return water header	Manual
	Not Shown	Individual Circuit	Temperature Flow	K Thermocouple Dial Thermometer Rotameter	Component exit Component exit Component entrance	Data Logger Manual Manual

A five-point calibration procedure is performed for each component in each data channel when the components are initially installed. This five-point procedure involves monitoring the output of each component at 0, 25, 50, 75 and 100 percent of the input range, and is conducted in both directions, that is, with an increasing input signal and then with a decreasing input signal. The same five point calibration procedure is conducted on each complete data channel at selected intervals; usually at the beginning of a new test program, and if and when there is a question about data quality.

4.2.3.5 Flue Gas Sampling

Combustion Products

Two flue gas sampling systems are available for the measurement of the combustion products. Figure 4.2-2 shows a schematic of the sampling flow-train. The first sampling system is shown in dashed lines and the second with solid lines. It should be noted that the first system is the primary system.

The first system uses a heated sampling line connected directly to a Perma Pure sampling system. The Perma Pure system is designed to condition the gas and vapor streams by continuous selective removal of particulates and water vapor, without loss of the gases being measured. Continuous filtration of gas sample streams that contain a high percentage of solids is made with a high-efficiency bypass filter. The gas sample passes through the inside surface of the filter at a high velocity through a Teflon eductor. Particulates and condensable vapors are bypassed, and the resulting gas sample stream will contain only particulates smaller than one micron. When acid gases are present, the bypass filter can be heated to prevent condensation and corrosion of the filter. Because the sample gas has been conditioned by the Perma Pure system, secondary dryers and filters down stream of the vacuum filter are bypassed. The moisture-free and particulate-free sample stream then goes to the control room to be analyzed.

In the second system, the sample gas passes through a cooling coil, where most of the condensate is drained, and a particulate filter prior to the vacuum pump. The second system shares the same vacuum pump used by the first system. After the vacuum pump, there is a dryer which is electrically heated to remove residual moisture in the sample stream. A second high-efficiency filter at a slightly lower temperature takes out fine

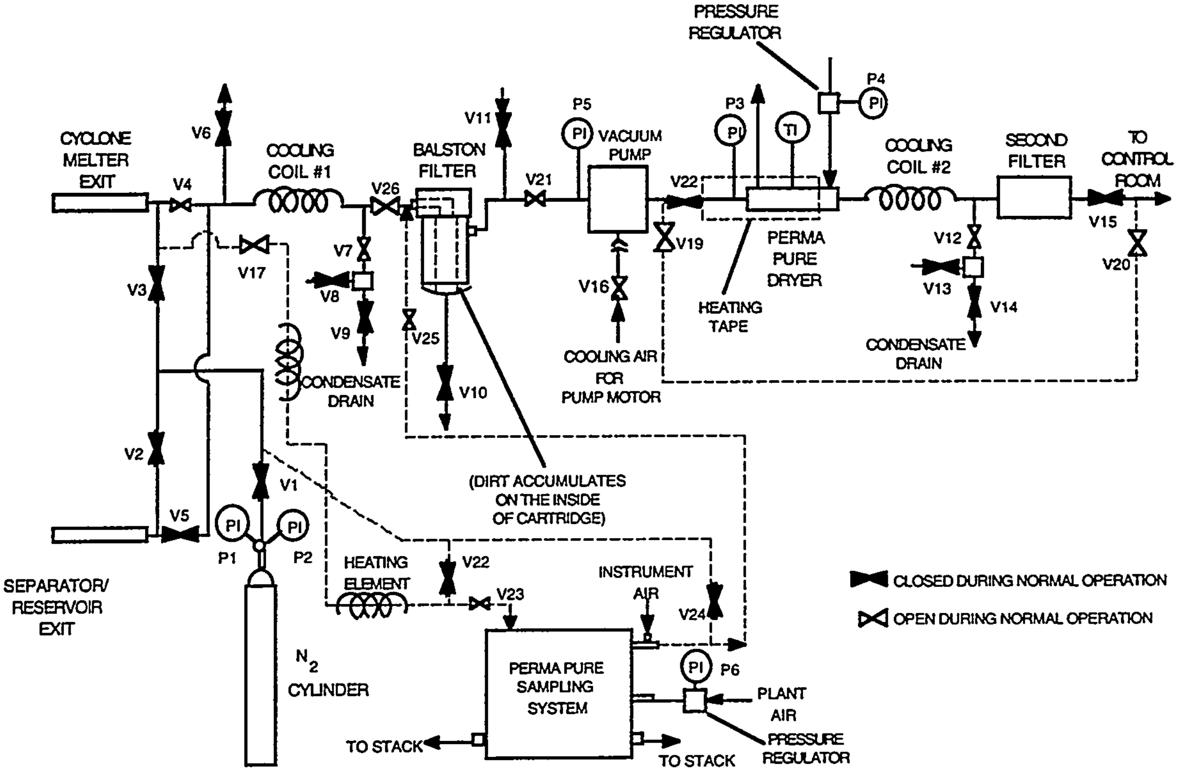


Figure 4.2-2 Instrumentation Process Schematic

particulates, while a dryer selectively removes the water vapor. The moisture-free and particulate-free sample stream then goes to the control room to be analyzed. A nitrogen purge is used on the sampling probes to remove possible material build-up. The flue gas sample is analyzed using Beckman series analyzers (Models 755, 870, 951, and 880 for O_2, CO, NO/NO_x, and SO_x, respectively). Measurement of total hydrocarbon and other chemical species may also be performed depending upon the objectives of the test.

Temperature

Process and component temperatures are measured in strategic locations to provide data for system operation and post test heat and mass balance analyses. The pilot facility uses thermocouples for all temperature sensing requirements. A list of all thermocouple tag numbers and a description of the function of each of the installed thermocouples is provided in Table 4.2.26a. All high temperature measurements (above 2000°F) within the CMS™ are made with Type S thermocouples (Platinum-10% Rhodium versus Platinum). All other temperatures are measured with Type K thermcouples (Chromel versus Alumel).

The principle temperatures for system heat and mass balance data are the temperatures of the preheated combustion air, transport air, natural gas, flue gas at the CMS™ exit, cooling water, and glass. Additional refractory temperatures and intermediate gas temperatures provide data for the start-up and operation of the system to insure that refractory temperatures do not exceed recommended rates of temperature change or maximum temperatures.

Referring to Figure 4.2-1, the temperature of the preheated combustion air is measured at each inlet arm location just prior to entering the CRV (downstream of Station No. 3). Combustion air temperature for the Emhart separator/reservoir burners is measured upstream of the air/gas mixer (Station No. 1). Combustion air for the Bloom separator/reservoir heat-up burner is measured upstream of the burner (Station No. 11). The transport air temperature is measured just prior to the air entering the pick-up trough of the pneumatic conveying system (Station No. 4). The natural gas temperature is measured at the main gas train mass flow station (Station No. 8). Flue gas temperature is measured for process control at the exit of the cyclone melter by a type S thermocouple which ends flush with the inside face of the CM outlet plate refractory (Station No. 7). Additional flue gas temperatures are measured in the separator/reservoir, the spray channel outlet to ensure sufficient cooling of the flue gas for method 5 stack sampling, and the WESP stack (Station No's. 9,12,13,14,15). The total cooling water inlet and outlet temperatures are measured as well as the outlet temperatures for each of the individual cooling circuits (Station No's. 17 & 18). Individual circuit temperatures are tied to alarms to maintain adequate cooling. In addition, cooling water temperature is used in conjunction with the cooling water flow to calculate the system heat loss. The glass temperature is measured in the separator/reservoir with a type S thermocouple mounted through the crown which is immersed in the glass upstream of the tap hole (Station No. 9).

In this report, glass temperatures typically refer to temperatures measured in the glass melt within the separator/reservoir. Cyclone reactor temperatures refer to flue gas temperatures measured at the exit of the cyclone melter (Station No. 8). Reactor temperatures within the CRV are typically not measured but are inferred from the temperatures at the exit of the cyclone melter and heat balance analysis.

Table 4.2.26a Test Facility Thermocouple Installation List

Tag Number	Thermocouple Description
TE-103	Temp Pond Water Supply
TE-106	Temp Pond Water Rtn CRV Lid
TE-111	Temp Pond Water Rtn CRV Lid
TE-116	Temp Pond Water Rtn CRV Body
TE-117	Temp Pond Water Rtn CRV Body
TE-118	Temp Pond Water Rtn CRV Body
TE-119	Temp Pond Water Rtn CRV Body
TE-141	Temp Pond Water Rtn CRV Cone
TE-146	Temp Pond Water Rtn CRV Cone
TE-151	Temp Pond Water Rtn CM
TE-156	Temp Pond Water Rtn CM
TE-161	Temp Pond Water Rtn CM
TE-165	Temp Pond Water Common Return
TE-166	Temp Pond Water Rtn separator/reservoir
TE-171	Temp Pond Water Rtn separator/reservoir
TE-172	Temp Pond Water Rtn separator/reservoir
TE-173	Temp Pond Water Rtn CRV Upper Arm
TE-201	Outside Air Temp
TE-204	Temp of Combust Air at Heater Inlet
TE-220	Temp of Combust Air at Inlet A
TE-221	Temp of Combust Air at Inlet B
TE-228	Combustion Air to Emhart Burners
TE-303	Combustion Air to Heater Exit
TE-403	Stack Temp
TE-404	Temp, Exh Gas at Scrubber Inlet
TE-407	Sep/Res Top Inlet Sec #1
TE-408	Sep/Res Top Inlet Sec #2
TE-409	Sep/Res Exit Sec # 1
TE-410	Sep/Res Exit Sec # 2
TE-411	Sep/Res Top Zone 3
TE-412	Sep/Res Top Zone 4
TE-413	Sep/Res Inlet Wall Zone 1 W
TE-414	Sep/Res Inlet Wall Zone 1 E
TE-415	Sep/Res Zone 3 Wall N
TE-416	Sep/Res Zone 2 Wall N
TE-417	Sep/Res Outlet Wall N
TE-418	Sep/Res Zone 3 Wall S
TE-419	Sep/Res Zone 2 Wall S
TE-420	Sep/Res Outlet Wall 1 SW
TE-421	Sep/Res Outlet Wall 2 S
TE-422	Sep/Res Outlet Wall 3 SE
TE-607	Temp Main Gas Supply
TE-614	CRV Exit S Gas Temp
TE-615	CRV Exit E Refractory Temp
TE-616	CRV Exit W Refractory Temp
TE-617	CRV Exit N Refractory Temp
TE-620	Gas Temp at Cyclone Melter Exit
TE-621	PC-'A' Top Sec Upper Tap Gas Temp
TE-622	PC-'A' Top Sec Middle Tap Ref Temp

Table 4.2.26a Test Facility Thermocouple Installation List (Cont'd)

TE-623	PC-'A' Top Sec Lower Tap Ref Temp
TE-624	PC-'A' Top SecNorth Gas Temp
TE-625	PC-'A' Inlet Arm "A" Gas Temp
TE-631	PC-'B' Top Sec Upper Tap Gas Temp
TE-632	PC-'B' Top Sec Middle Tap Ref Temp
TE-633	PC-'B' Top Sec Lower Tap Ref Temp
TE-634	PC-'B' Top SecNorth Gas Temp
TE-635	PC-'B' Inlet Arm "B" Gas Temp
TE-640	Gas Temp at separator/reservoir Exit
TE-713	Temp Transport Air
TE-903	Temp Oxygen Flow

Particulates

The APC system consists of a flue gas quench assembly, a wet electrostatic precipitator (WESP), two recirculation tanks (one for the quench assembly and one for the WESP), and two water pumps. A slip stream is also pumped from the recirculation tanks and sent to a particulate filter, where the particulate material is removed and the water is recycled back to the recirculation tanks. The particulate is periodically removed from the filter, dried, and recycled backed to the batch tank for blending with original batch materials.

Provisions were made to use clean city water as the collection medium during sampling. When the particulate flow in the quench system was being sampled (location S5), the recirculating flow that carries particulate to the settling tank, was interrupted by adjusting a three-way valve and passing clean water through the spray nozzles of the quench system. Another three-way valve was used to divert all of the flow from the quench system exit line into the container used to collect the particulate laden water. The collection process lasted approximately five minutes. After the sample was collected, both three-way valves were closed, placing the system back in the recirculation mode.

The time to fill a 55-gal. container was measured with a stop watch. Once the container was filled to approximately three-quarters of its capacity, it was sealed, and the next measurement was made using another container. After the test is completed, each container was weighed. The flow rate is the quotient of net weight and time to fill.

The containers were set aside for several days to allow the solids to settle out, after which the solids were filtered from the water. The solids were dried and weighed. Again, the flow rate is the quotient of net weight and time to fill the container.

The particulate in the flue gas leaving the quench assembly was sampled during the test by an EPA Method 5 test procedure. Stack gas sampling was conducted at location S4 by a qualified analytical laboratory, Comprehensive Safety Compliance (CSC), using the protocol described in Section 3.0 of the *Methods Manual for Compliance with the Boiler and Industrial Furnace Regulations.* This particular section is entitled "Sampling and Analytical Methods" and describes the sampling and analytical procedure for determining the metals content of the flue gas. The laboratory analytical procedures to determine the metals content of the samples are consistent with and refer to the methods described in SW-846. The Method 5 sampling location is a point in the duct between the quench assembly and the WESP; therefore, there was no need to sample the particulate in the WESP.

4.2.3.6 Feedstock and Vitrified Product Streams Sampling

The experimental system at U-PARC provides for relatively easy access to feedstock materials and vitrified products. Feedstock and vitrified product samples were collected in appropriate vessels (e.g., glass, polypropylene, polyethylene, stainless steel). The feedstock and product were sampled throughout the tests in accordance with the sampling schedule shown in Table 4.2-27. Selected samples have been sent to qualified laboratories for analysis.

4.2.3.7 Test Operation and Results

The operational time on the CMS™ during the demonstration test totaled approximately 105 hours over five days. The unit was started on natural gas and ramped up to temperature over a 24 hour period of time beginning at approximately 7:30 a.m. on September 11, 1994. A log of the test identifying significant changes in system operation and plots of the major system parameters (identified in Table 4.2-28) over the period from September 12, the first day feedstock melting, to September 16 are included as Appendix A in this report. All parameters were continuously recorded except for emissions data. Emissions date were recorded during Method 5 flue gas sampling periods. Feedstock flow was initiated at approximately 9:45 a.m. on September 12, still with natural gas as the primary fuel. Operation was continued on natural gas over the next 12 hours to stabilize the system with a feedstock flowrate of approximately 1,200 lbs/hr. Although this is not the maximum

Table 4.2-27
Sampling Schedule

Measurement	Sample Site	Frequency	Remarks
Feedstock Flowrate	Batch Tower (S1)	Continuously	Monitored by system computer
Feedstock Composition	Batch Tower (S1)	Sampled just prior to test	Sampled from batch tank
Glass composition	Cullet Cart (S2)	30-minute intervals	Ladle samples and cullet samples
Spray Channel water flowrate	Quench Exit (S5)	30-minute intervals during EPA Method 5 test	Measure time to fill known volume
Spray Channel water composition	Quench Exit (S5)	30-minute intervals during EPA Method 5 test	Samples taken as flowrate is measured
Spray Channel particulate composition	Quench Exit (S5)	30-minute intervals during EPA Method 5 test	Samples taken as flowrate is measured
Flue Gas flowrate	Exhaust Stack (S4)	Once during EPA Method 5 test	EPA/530-91-010
Flue Gas particulate flowrate	Exhaust Stack (S4)	Once during EPA Method 5 test	EPA/530-91-010
Flue Gas composition O2, CO, SO2, NOx	Exhaust Stack (S4)	Continuously	Monitored by system computer
System parameters: Temperature, Pressure, Flow	see Figure 4.2-1	Continuously	Monitored by system computer

Table 4.2-28
Major System Parameters for Which Data is Provided in Appendix A

Total Fuel Thermal Input
Natural Gas Thermal Input
Coal Thermal Input
Total Combustion Air Flow
Calculated Actual-to-Stoichiometric Air Ratio
Feedstock Flow Rate
Cyclone Melter (CM) Exhaust Gas Temperature
Calculated CMS™ Heat Rate
Oxygen Concentration in Flue Gas
Measured NO_X Concentration in Flue Gas
NO_X Concentration in Flue Gas Corrected to 3% O_2
Measured CO Concentration in Flue Gas
CO Concentration in Flue Gas Corrected to 3% O_2
Measured SO_2 Concentration in Flue Gas
SO_2 Concentration in Flue Gas Corrected to 3% O_2

amount of feedstock that can be processed by the pilot-scale CMS™ (flowrates as high as 2,100 lbs/hr were achieved), it has been established during previous tests to be an operating point which provides for a comfortable margin between the required operating fuel and combustion air flow rates and the maximum capacity of their supply subsystems.

Coal flow was initiated at approximately 8:00 p.m. on September 12 at a rate sufficient for the coal to provide approximately 70% of the total thermal input to the CMS™. Over the next four days the system was operational for a total of approximately 91 hours, approximately 46 hours of which were with coal as the primary fuel providing between 70% and 100% of the thermal input to the CMS™, and approximately 50,000 lbs of feedstock material was vitrified. No problems were encountered with the CMS™ components during the test. However, problems were encountered with solids buildup in the flue gas quench duct and the quench spray water drain line which necessitated periodic cleanout of the duct and drain line. Cleaning of the duct and drain line generally took approximately 1 hour. The flue gas quench duct is located immediately downstream of the glass separator/reservoir. This configuration allowed for the use of carbon steel piping from the exit of the separator/reservoir to the WESP and provided sufficient distance between the quench duct and the WESP to avoid interference of the spray water with flue gas sampling equipment. However, the rapid quenching of flue gas from approximately 2500°F to 600-800°F results in a significant amount of the particulate carryover being captured by the quench water and carried with the water through the drain line. A commercial system would include a recuperator for combustion air preheating and an evaporative cooler downstream of the separator/reservoir. This would result in more gradual cooling of the flue gas and would minimize the excess water injected into the flue gas. Proper design of this downstream equipment in a commercial process would mitigate the problem encountered in the pilot-scale testing.

Vitrified Product Analysis

Samples of glass taken during the test when firing on natural gas alone, co-firing natural gas and coal, and firing on coal alone were analyzed by Corning Engineering Laboratory Services (CELS) for chemical composition. The results of the analysis, presented in Table 4.2-29, show little difference in the glass compositions for the different fuels.

Table 4.2-29
Quantitative Chemical Analysis of Vitrified Product Sample from Demonstration Test

	Concentration (Wt. %)		
Oxide	Sept. 12 Sample Nat. Gas Firing	Sept. 12 Sample Co-Firing (50/50)	Sept. 14 Sample Coal-Firing
SiO_2	35.5	37.3	36.9
Al_2O_3	19.3	21.8	21.3
CaO	16.2	18.4	18.0
MgO	10.6	12.1	11.9
Fe_2O_3	8.74	8.80	8.99
SO_3	0.01	0.02	0.01

Differential Thermal Analyses (DTA) were also performed on samples from each of the days of operation and the results compared to the glass sample with natural gas firing analyzed by CELS to assess the consistency of the product over the duration of the test. Differential Thermal Analysis (DTA) is useful for characterizing materials by the heat emitted or absorbed by a sample during the heating or the cooling of a sample. The heat emitted or absorbed by the sample is due to phase transformation or chemical reaction occurring in the material. The temperature and the amount of heat emitted or absorbed by a material is strongly dependent on the chemical and phase composition of that material. Therefore, this is a useful method for observing variations in the overall properties of a material.

The principle of DTA is to heat a sample and a reference material at a constant rate and measure their temperature difference. The reference material is selected such that no reactions will occur over the given temperature range of the analysis. Therefore, the rate of temperature increase or decrease of the reference material will remain constant. If a reaction occurs in the sample material, the temperature will increase at a greater rate if the reaction is exothermic (heat is emitted by the sample) or at a slower rate if the reaction is endothermic (heat is absorbed by the sample). Additionally, if there is a change in the heat capacity of the material, which may be associated with a phase change, the heating rate of the sample material may change. In DTA analysis, the temperature difference between the sample and reference material is determined by the potential difference of thermocouples mounted close to the sample and reference material. To obtain a DTA curve, the temperature or potential difference between the sample and reference thermocouples is plotted as a function of temperature.

DTA can be used to identify two regions in glasses, the glass transition temperature and the crystallization temperature of various phases. Both of these processes were clearly visible in the DTA curves collected from the demonstration test glass samples. A sample curve collected from a demonstration test glass sample is shown in Figure 4.2-3. Insignificant features in this plot include structures in the curve below 500°C (related to the sample and reference cup equilibrating with the furnace) and the curve dropping from 1110°C to 600°C (cooling curve of the furnace).

The glass transition temperature, T_g, refers to the temperature range over which the phase of a material changes from a super cooled liquid to a glass. Associated with this phase transition is an increase in the heat capacity of the glass with increasing temperature. This increase in the heat capacity of the glass leads to a decrease in the DTA curve with increasing temperature. This is illustrated in Figure 4.2-3 at approximately 700°C. T_g in this investigation was found by constructing a tangent above and below the transition temperature. The intersection of these two lines defines T_g as marked in the figure. The size of the temperature step is an indication of the magnitude of the change in the heat capacity. This value is marked as Δ @ T_g in the figure.

Crystallization in glass melts is an exothermic reaction. This reaction is related to crystalline phases precipitating from the melt above the glass transition temperature. The crystallization process leads to a peak in the DTA curve as observed in Figure 4.2-3 in the region of 990°C. The peak crystallization rate described as the peak maximum is marked as T_{Peak} in the figure. The peak height is an indication of the amount of heat that is liberated during the crystallization process.

The DTA curves collected from the demonstration test glass samples were characterized by the glass transition temperature, the step size at the glass transition temperature, the peak crystallization rate, and the height of the crystallization peak. The heating of the furnace for

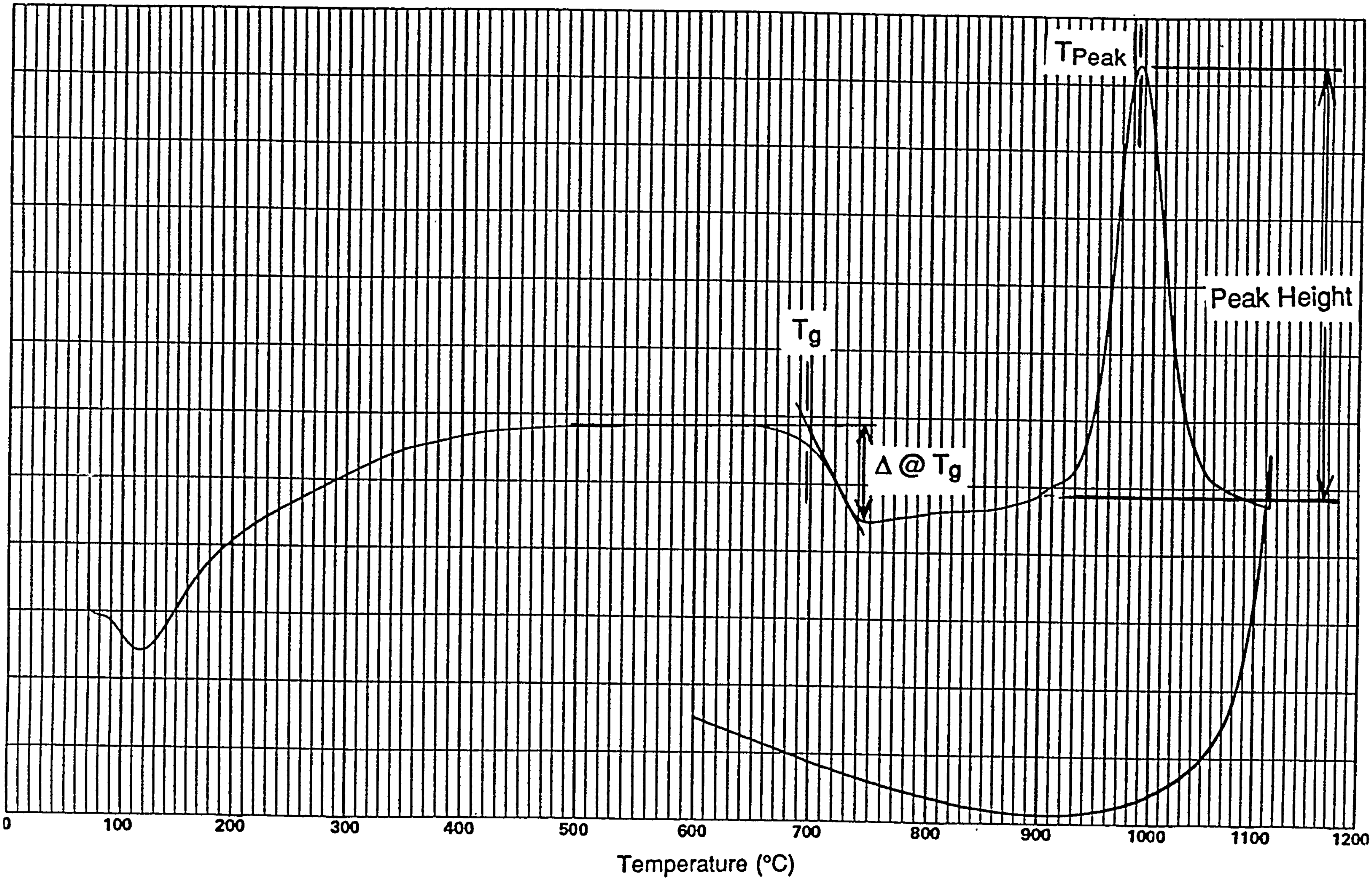


Figure 4.2-3. DTA Curve for Reference Glass Sample

all of the samples was 15°C/min. Table 4.2-30 summarizes the results from glass samples selected during each day of the test. To determine the expected variations in the DTA curves from a constant composition, three DTA curves were collected from the glass sample taken on 9/12/94 at 12.25 pm. Slight variations observed are related to local variations in the material and possibly the particle size distribution of the DTA sample.

The characteristics observed from the glass samples collected on various days did not vary significantly out of the range observed for the 9/12/94, 12.25 pm sample. This indicates a consistency in the overall product properties (chemical and phase) over the duration of the melter operation.

Refractory Evaluation

Three different refractories were employed in the CMS™. A bonded AZS refractory from North America was installed in the cyclone melter backed by 2 inches of insulating refractory. A low-cement AZS castable from Corhart was installed in the cylindrical section of the CRV combustor, and a low-cement AZS castable from Zedmark was installed in the cone section of the CRV combustor. Both of these refractories were actively cooled by the water-cooled steel CRV combustor shell.

The internal diameter of the CRV combustor and the cyclone melter was measured at various locations both before and after the demonstration test to evaluate refractory wear. Low cement castables do not typically perform as well as bonded refractories. However, the change in the inside diameter of the CRV combustor ranged from approximately 1/4 inch to 1/2 inch (1/8 to 1/4 inch refractory wear); whereas, the change in the cyclone melter ranged from approximately 2 to 2-1/2 inches (1 to 1-1/4 inch refractory wear). Therefore, the active cooling of the castable refractory had a very significant impact on the refractory wear rate. Again it must be noted that the refractories used in the pilot scale test loop have not been optimized for use with the feedstocks utilized in the testing. The refractories selected were chosen as a compromise between thermal shock resistance and corrosion/erosion because of the frequent and rapid start-up and shutdown requirements of the test system. The majority of commercial applications are base load operations; that is, the CMS™ would operate continuously at operating temperature. The feedstock flow to

Table 4.2-30
Vitrified Product DTA Data From Demonstration Test

Sample	T_g (°C)	Step Size @ T_g (μV)	T_{Peak} (°C)	Peak Height (μV)
Test 93, 9/12/94 12:20 PM	695	34.4	987	184
Test 93, 9/12/94 12:25 PM	698	31.2	982	175
Test 93, 9/12/94 12:25 PM	700	34.4	989	172
Test 93, 9/12/94 12:25 PM	702	31.2	990	188
Test 93, 9/13/94 1:00 PM	700	34.4	980	184
Test 93, 9/14/94 12:35 PM	696	34.4	986	162
Test 93, 9/15/94 11:00 PM	703	34.4	978	162
Test 93, 9/16/94 9:10 AM	701	34.4	1004	156

the system can be terminated and restarted instantaneously; therefore, for applications where glass production is interrupted for short periods of time (eg. one shift or weekend), the systems can be economically "idled" at or near operating temperature. Therefore, in a commercial application, the refractory can be optimized with respect to corrosion/erosion rate for the feedstock being processed.

Thermal Efficiency

The thermal input to the CMS™ generally ranged from approximately 3.5 million Btu/hr to 4.5 million Btu/hr, at the nominal feedstock flow rate at approximately 1,200 lbs/hr, and gas temperature of the exit of the cyclone melter in the range from 2450°F to 2600°F. The heat rate, therefore, ranged from approximately 6 million Btu/ton of feedstock (7.5 million Btu/ton vitrified product) to 8 million Btu/ton of feedstock (10.3 million Btu/ton vitrified product) at these conditions. At steady state operating conditions, the heat rate during the demonstration test ranged from a low of approximately 5 million Btu/ton of feedstock at feedstock flowrates above 1700 lbs/hr to a high of approximately 12 million Btu/ton at 550 lbs/hr feedstock flow rate.

On the final day of the test, January 16, the feedstock flow rate was increased to the maximum that could be achieved while maintaining constant cyclone melter exit temperature. The limitation was the quantity of natural gas and combustion air that could be delivered to the CMS™ by the respective subsystems. The feedstock flowrate was increased on two occasions on the last day, the first with approximately 10% excess combustion air delivered to the system and the second with 25% - 30% excess air. The first time, a feedstock flowrate of approximately 2,100 lbs/hr was achieved with a thermal input (100% coal) of approximately 5.5 million Btu/hr and a cyclone melter exit gas temperature of approximately 2500°F. The resulting heat rate, therefore, is approximately 5.2 million Btu/ton of feedstock. The second time, a feedstock flowrate of approximately 1,700 lbs/hr was achieved with a thermal input (again with 100% coal) of about 4.5 million Btu/hr and a cyclone melter exit gas temperature of approximately 2425°F. The resulting heat rate is approximately 5.3 million Btu/ton of feedstock. The vitrified product during this period of operation is similar in appearance to the product during the lower feedstock flowrate periods, as are the chemical composition and differential thermal analyses results. The primary difference in operating characteristics of the CMS™ during the period of high feedstock flowrate relative to the rest of the test was increased CO emissions. This was primarily a result of the reduced gas residence time in the CMS™ associated with the higher combustion air and fuel flowrates, as is discussed further in the following section.

Representative heat and mass balances for the test are shown in Figures 4.2-4 and 4.2-5. The balance in Figure 4.2-4 represents an average for the period beginning at 12:35 p.m. and ending at 1:45 p.m. on September 12, 1994 with natural gas as the fuel. The balance in Figure 4.2-5 represents an average for the period from 9:00 a.m. to 9:30 p.m. on the last day of the test, September 16, 1994, with coal as the primary fuel.

Emissions Analysis

Flue gas was periodically sampled on-line and analyzed for O_2, CO, NO_x, and SO_2 during the demonstration test using Beckman series analyzers as described in Section 4.2.3.5. Additionally, modified EPA Method 5 sampling of the flue gas before the WESP was conducted once each day of the test to determine the amount of particulate carryover in the gas.

Expanded plots of O_2, CO, NO_x, and SO_2 during the periods of time on each day when the EPA Method 5 flue gas sampling were conducted are shown in Figures 4.2-6 through 4.2-21. O_2 concentration in the flue gas was nominally 4% and ranged from 2% to 6%. CO concentration was 200 ppmv to 1,000 ppmv when firing with 100% coal and typically 100 ppmv to 150 ppmv when firing with natural gas. On the last day when the feedstock flow rate was increased to 1,700 lb/hr - 2,100 lb/hr, the CO concentration in the flue gas

Graphical Summary of the Heat and Mass Balance
Data for Test 93-1 @ 12:35 - 13:45, September 12,1994

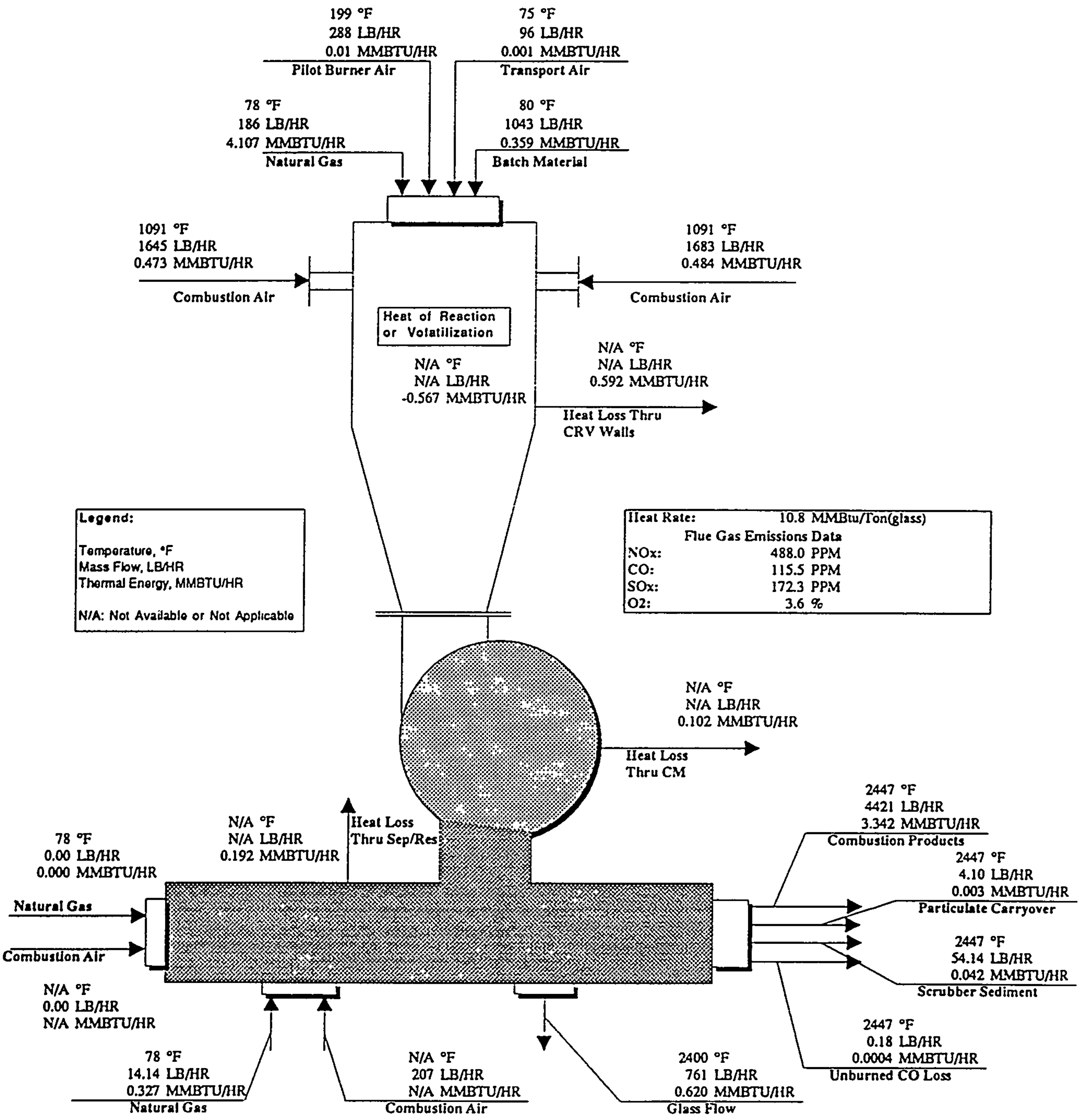


Figure 4.2-4
Graphical Summary of the Heat & Mass Balance
Data for Test 93-1 @ 12:35 - 13:45, September 12, 1994

Graphical Summary of the Heat and Mass Balance
Data for Test 93-5 @ 9:00 - 9:30, September 16,1994

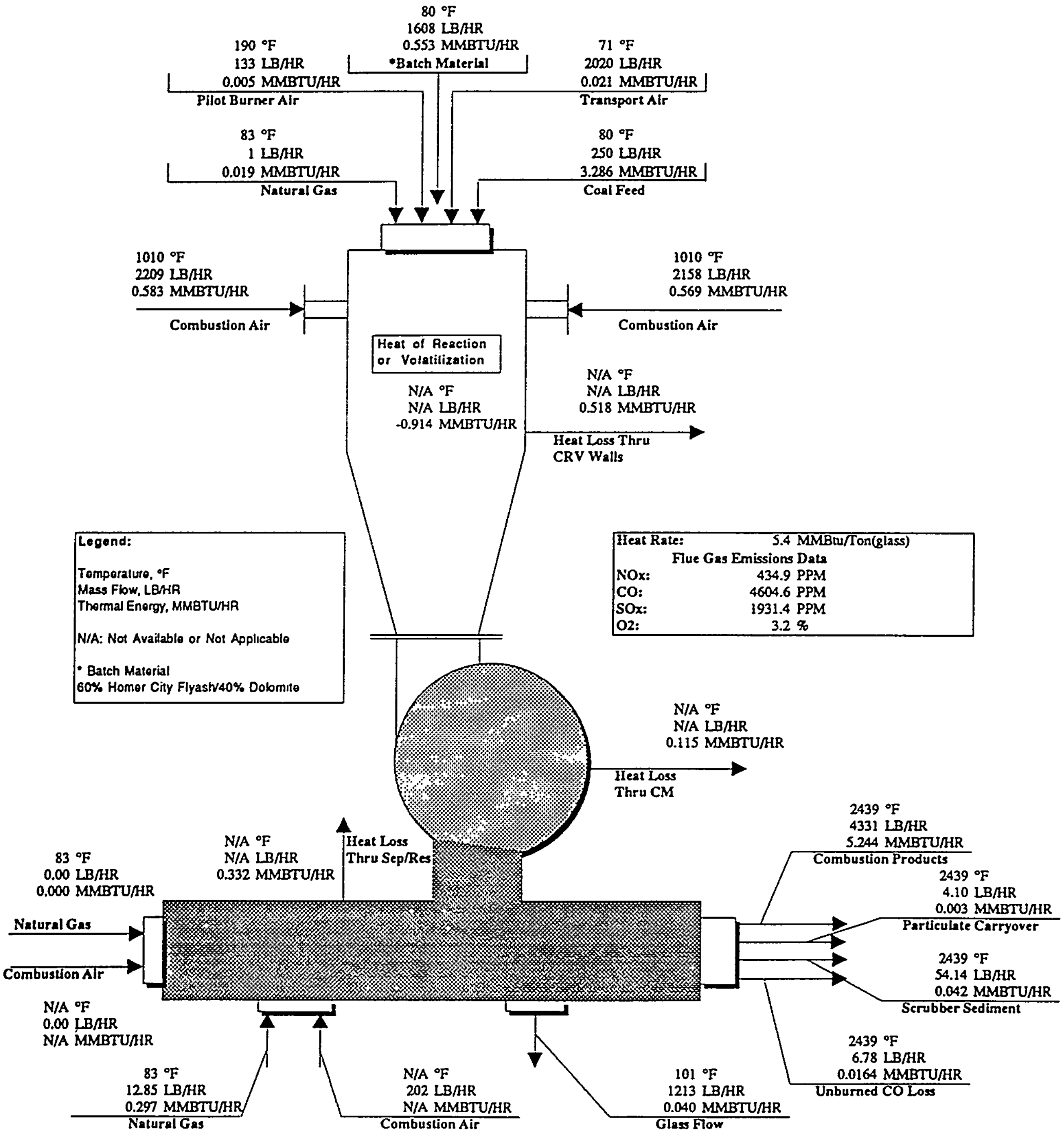


Figure 4.2-5
Graphical Summary of the Heat & Mass Balance
Data for Test 93-5 @ 9:00 - 9:30, September 16, 1994

Figure 4.2-6

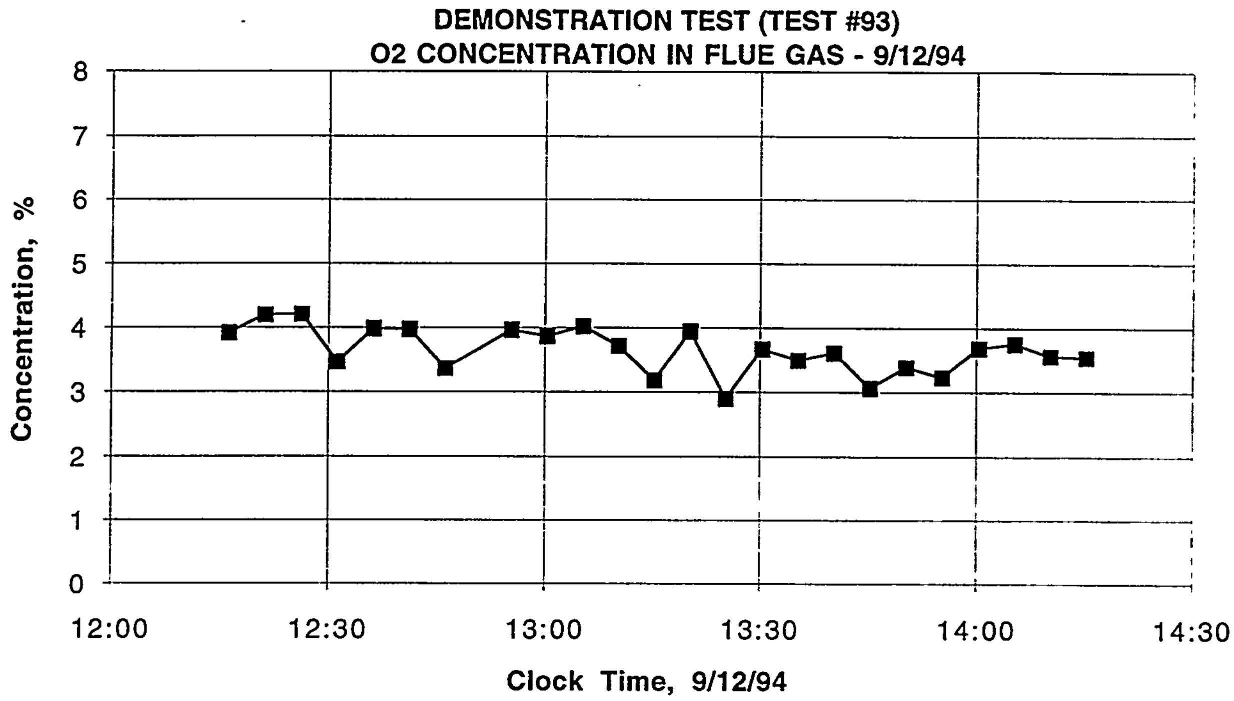


Figure 4.2-7

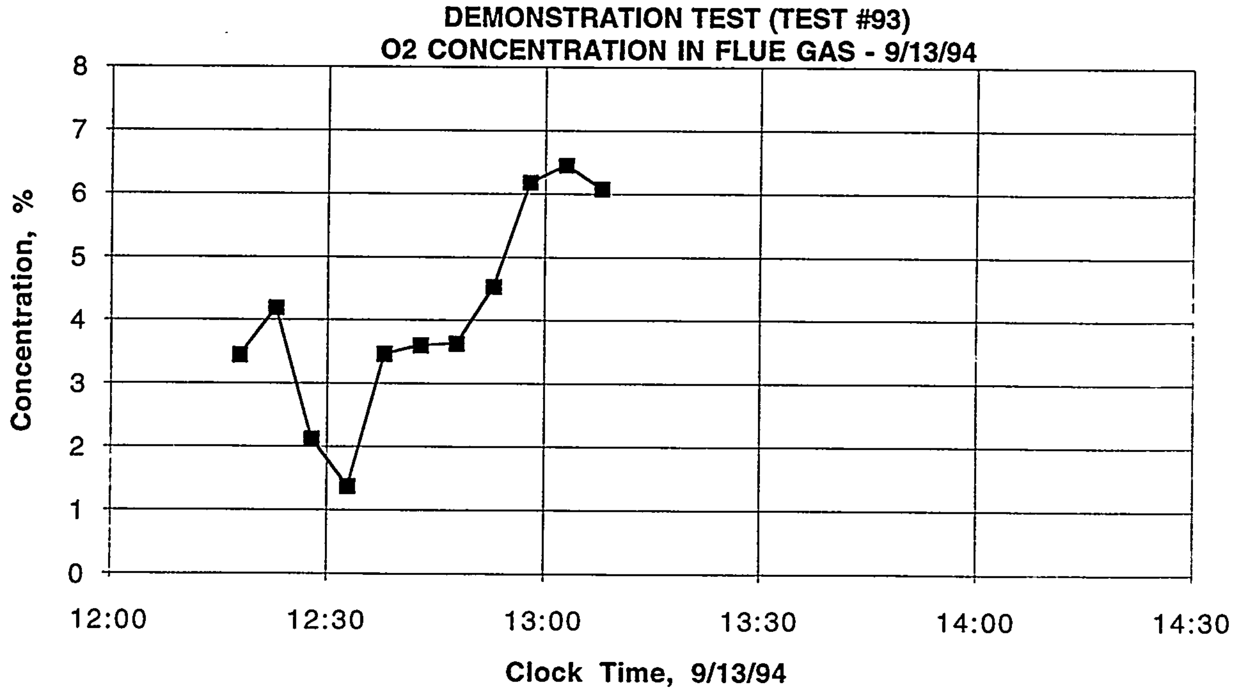


Figure 4.2-8

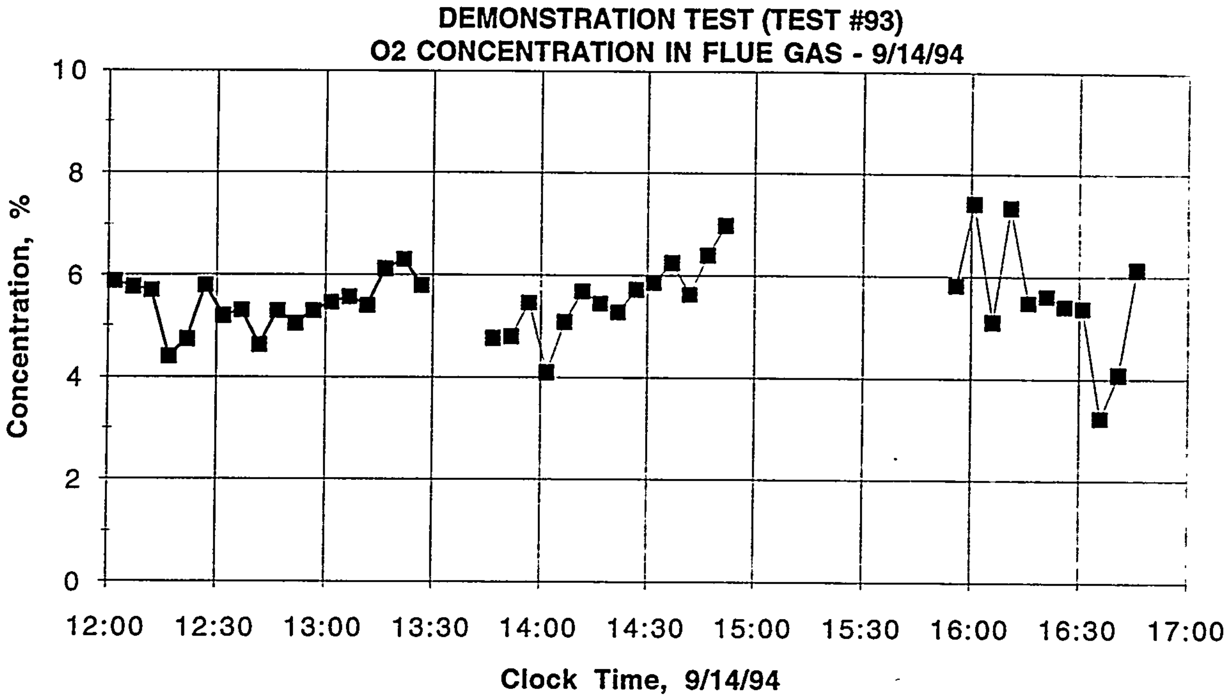


Figure 4.2-9

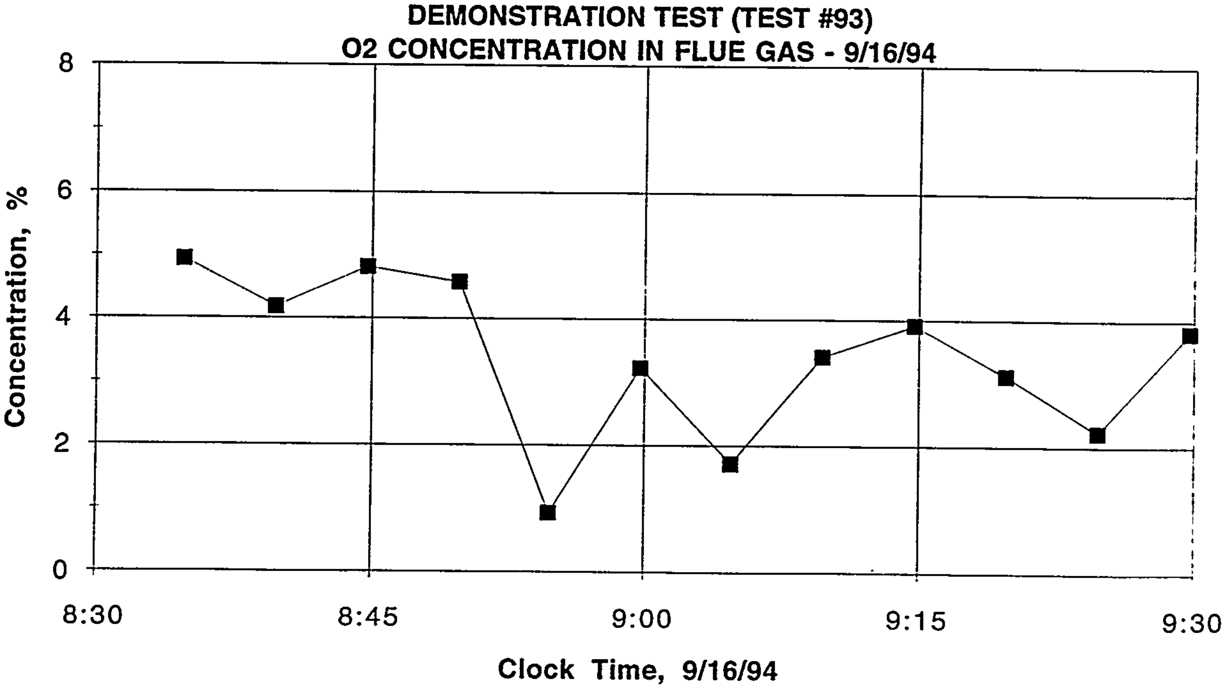


Figure 4.2-10

DEMONSTRATION TEST (TEST #93)
CO CONCENTRATION IN FLUE GAS - 9/12/94

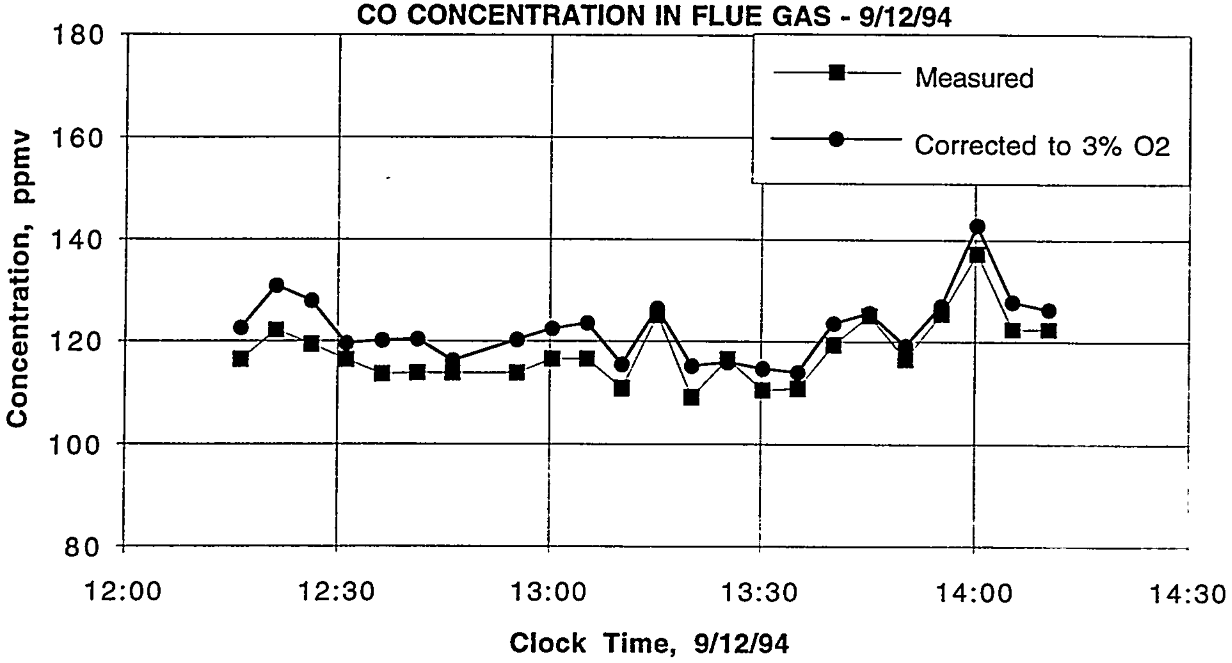


Figure 4.2-11

DEMONSTRATION TEST (TEST #93)
CO CONCENTRATION IN FLUE GAS - 9/13/94

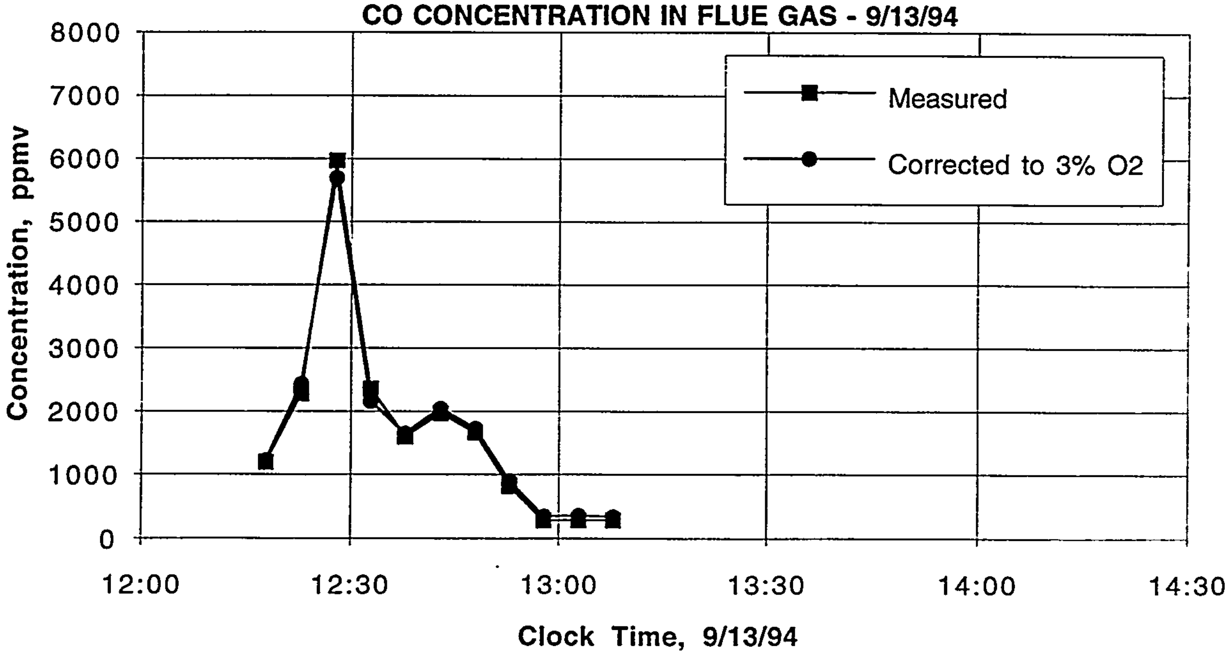


Figure 4.2-12

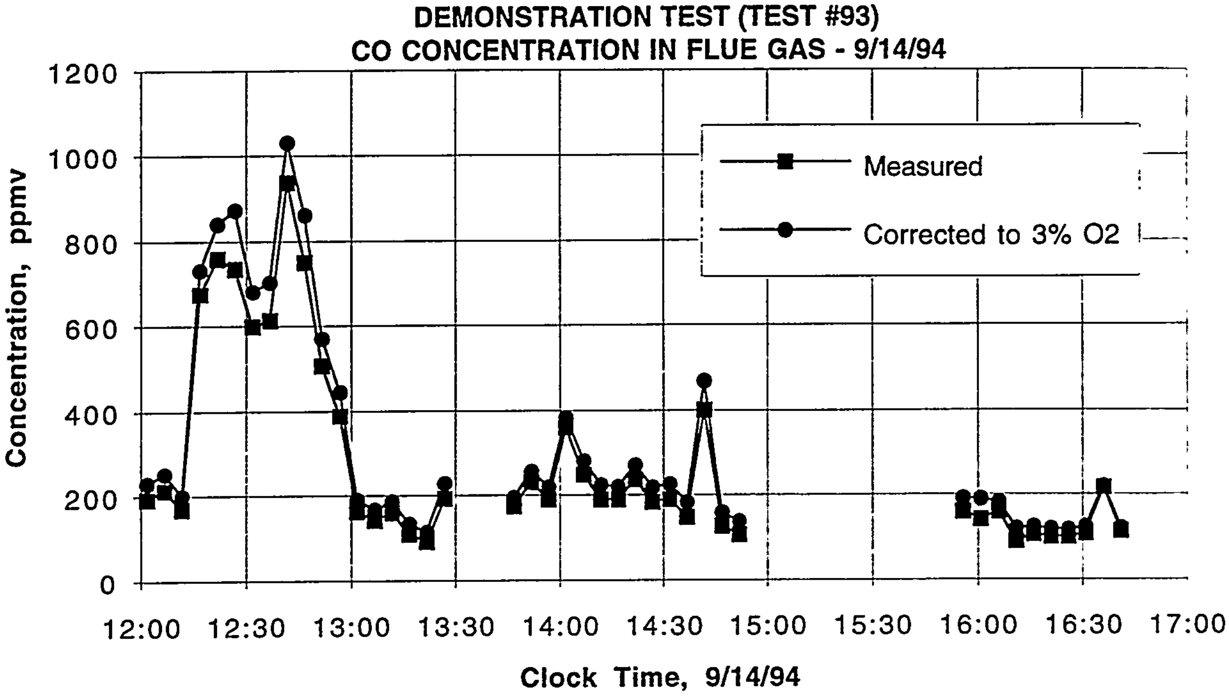


Figure 4.2-13

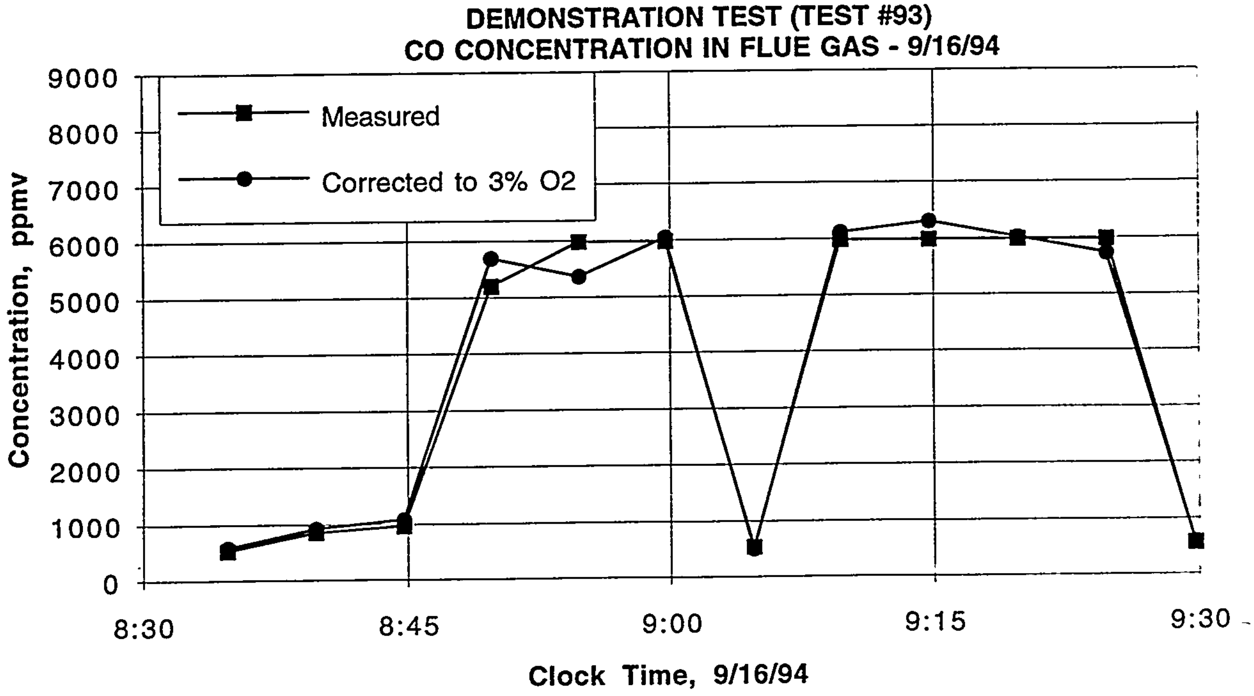


Figure 4.2-14

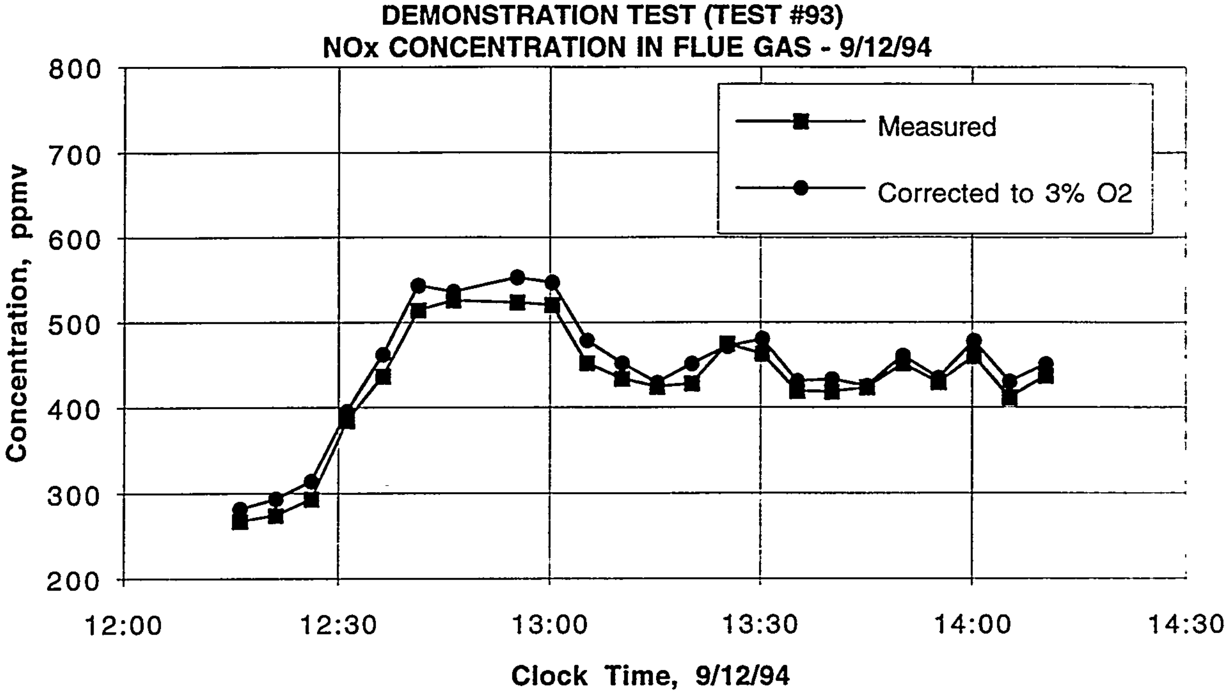


Figure 4.2-15

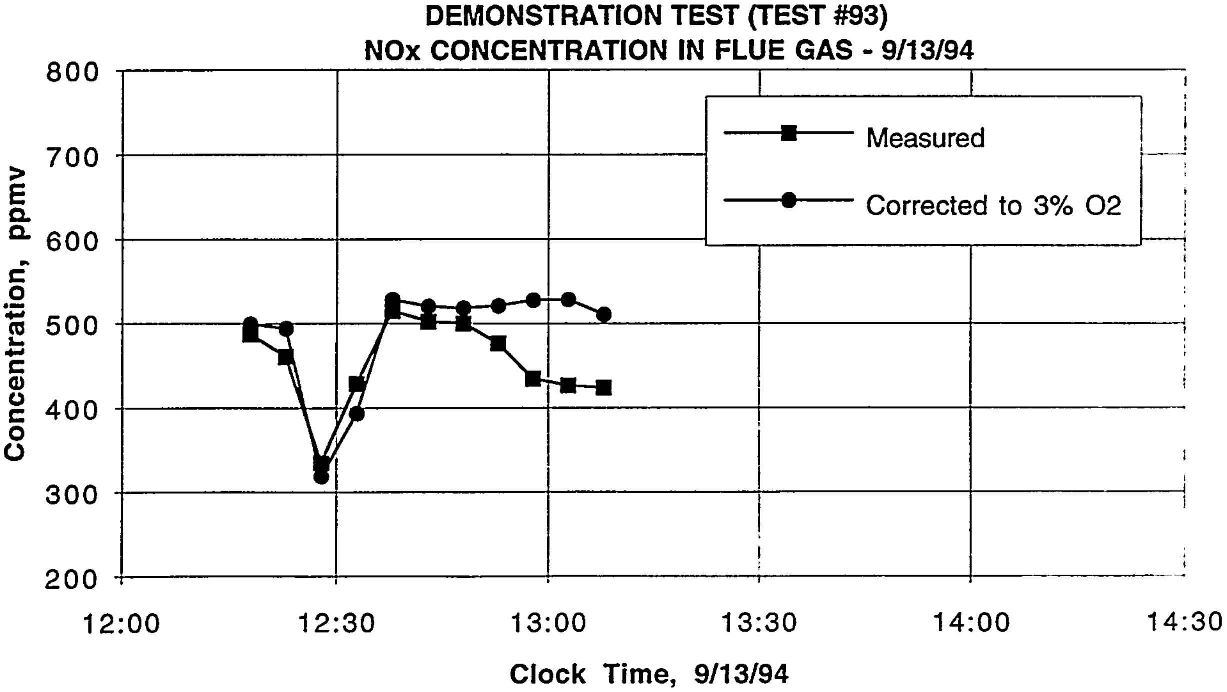


Figure 4.2-16

DEMONSTRATION TEST (TEST #93)
NOx CONCENTRATION IN FLUE GAS - 9/14/94

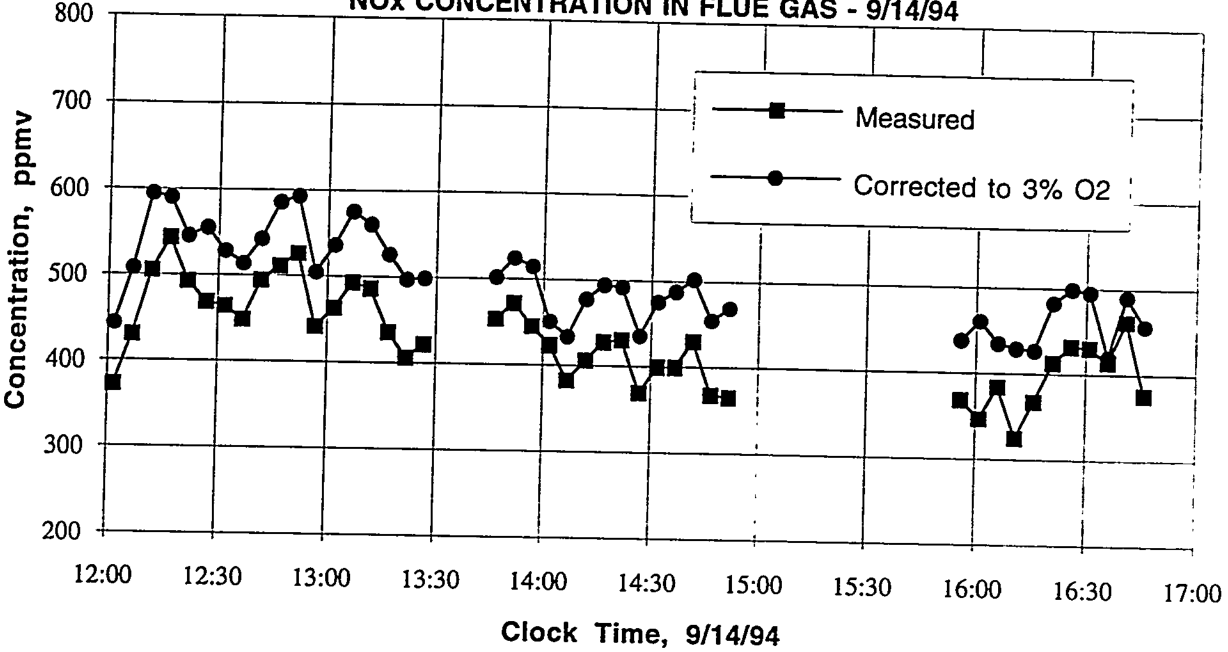


Figure 4.2-17

DEMONSTRATION TEST (TEST #93)
NOx CONCENTRATION IN FLUE GAS - 9/16/94

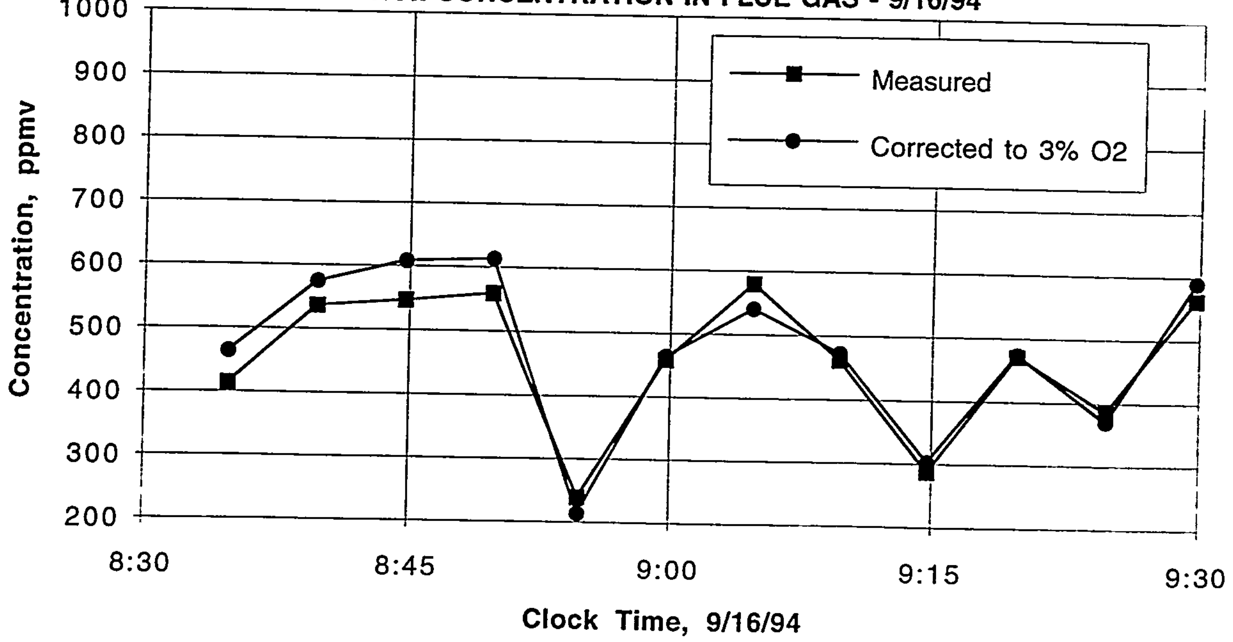


Figure 4.2-18

DEMONSTRATION TEST (TEST #93)
SO2 CONCENTRATION IN FLUE GAS - 9/12/94

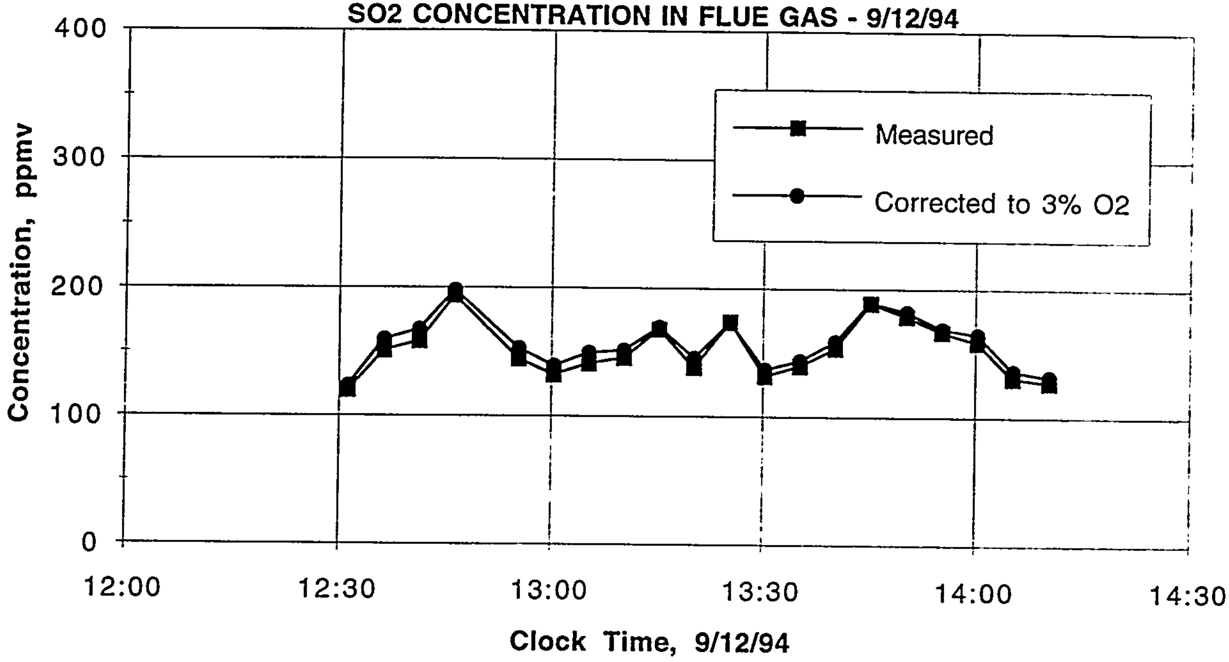


Figure 4.2-19

DEMONSTRATION TEST (TEST #93)
SO2 CONCENTRATION IN FLUE GAS - 9/13/94

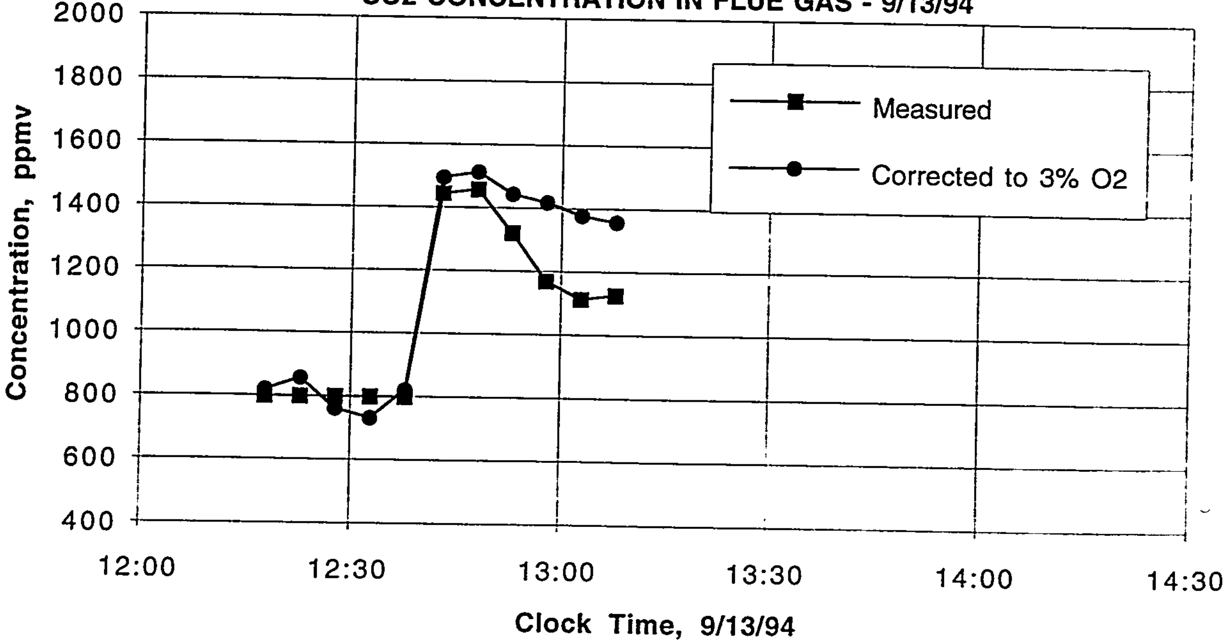


Figure 4.2-20

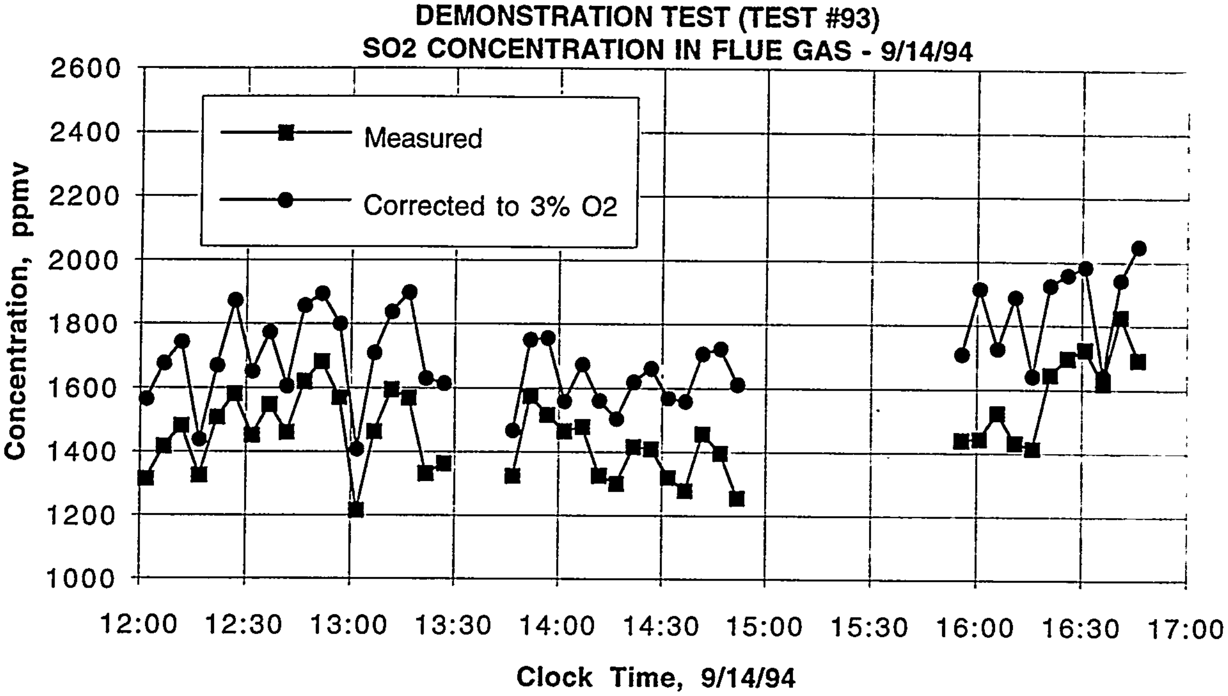
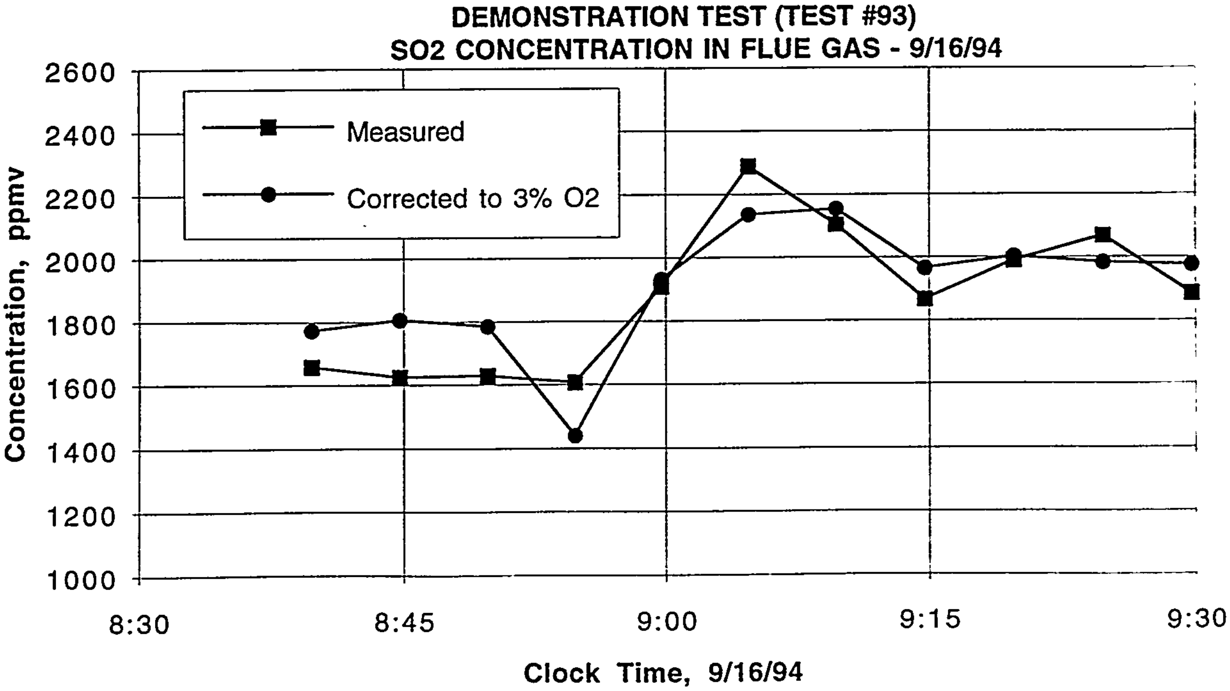


Figure 4.2-21



increased to approximately 7,000 ppmv (the limit on the on-line instrumentation is 6,000 ppmv, but a sample taken by the outside laboratory conducting the Method 5 sampling showed approximately 7,000 ppmv CO). This is probably due to the reduced combustion gas residence time in the CMS™ associated with the higher combustion air and fuel flow. It is important to note that the gas residence time in the pilot-scale CMS™ is less than 0.5 second. A commercial CMS™ process would have 2 seconds or more gas residence time at gas temperatures above 1800°F because of scale-up factors and the addition of a recuperator downstream of the separator/reservoir for combustion air preheating. The additional residence time should be more than sufficient to convert the CO to CO_2 even at the higher concentrations.

NO_x concentration in the flue gas was typically 400 ppmv to 500 ppmv reported as NO. At the maximum feedstock flowrate this is equivalent to 4.5 - 5.5 lb NO per ton of glass. Based on the nitrogen content of the coal (≈1.4%) and flyash (≈0.02%), if all of the nitrogen in these feed streams were converted to NO, then the NO concentration in the flue gas from coal and ash alone would be approximately 1800 ppmv. Regulations with respect to NO_x emissions are site specific. California currently has the most stringent regulation with a standard of 4.5 lb/ton.

SO_2 concentration in the flue gas was nominally 150 ppmv when firing with natural gas and 1500 ppmv to 1700 ppmv when firing with 100% coal. At the high feedstock flowrate, the SO_2 concentration increased to approximately 2,000 ppmv. A detail sulfur balance calculation shows that these are the levels of SO_2 concentration that would be expected if all of the sulfur contained in the coal (≈2%) and the flyash (≈0.2%) were converted to SO_2 in the system.

Results of the flue gas sampling for particulate carryover analysis indicated that uncontrolled particulate carryover (at the exit of the separator/reservoir) was consistently about 5% of the feedstock flowrate. Typically, approximately half of the carryover was removed from the flue gas by the quench water immediately downstream of the separator/reservoir.

4.3 COMMERCIALIZATION PLANS / ECONOMIC ASSESSMENT

4.3.1 Target Markets

As a result of the market studies and commercialization efforts performed by Vortec, we have identified several target markets for the CMS™ technology. These target markets include:

1. Recycling of industrial solid wastes into value added by-products
2. The remediation of hazardous and radioactive wastes
3. Commercial glass melting and waste glass recycling applications

The primary advantages of the CMS™ technology relative to current and competing technologies in these markets are its ability to rapidly melt inorganic constituents in feedstocks using a variety of fuels and the efficient oxidation of organic constituents which could otherwise be hazardous pollutants. Both of these advantages are provided by the efficient heating of feedstock in suspension with the products of combustion and excess air/oxygen in the process. As a result, the high temperature components comprising the process are smaller in physical size than conventional melting components and thus have lower structural heat losses. This results in higher thermal efficiencies and lower capital and operating costs.

4.3.2 Commercialization Activities and Economics

As a result of our commercialization efforts, Vortec has been successful in achieving commercial implementation of the technology. Two commercialization projects are currently under construction and several other projects are currently under negotiation. Our first project to be commercially implemented involves the recycling of industrial solid wastes into value added by-products. The second commercial scale project involves the remediation of radioactive and hazardous wastes. Several other projects involving commercial glass melting and waste recycling are currently under negotiation.

4.3.2.1 Industrial Waste Recycling

The CMS™ has demonstrated the ability to recycle a variety of industrial solid wastes. Waste materials which have been qualified via demonstration testing under the current PETC contract and/or other SBIR or commercial grants have included:

coal fired boiler ash
municipal incinerator flyash
sewage sludge incinerator ash
spent pot liners from aluminum smelting operations
metal plating wastes
electric arc furnace dust

- foundry sand, and
- automobile shredder residue ash.

By-products which can be produced from these waste materials include:

- asphalt shingle granules
- ceramic tile
- mineral wool
- abrasives
- bricks
- concrete products
- asphalt concrete
- glass frits

For commercial implementation, Vortec has developed means for producing value glass and ceramic product by incorporating the use of one or several waste forms into the feedstocks of a melting operation. Not all of the listed by-products can be made from all of the listed waste forms. Validation tests are required to qualify the production of specific by-products from selected combinations of industrial wastes. Essentially all of the by-products listed have been qualified to some extent for commercial acceptance by the end-user industries. For example, we have had our asphalt shingle granules qualified by several asphalt shingle manufacturers. Our ceramic tile products have been qualified by major ceramic tile manufacturers. In this latter case, Vortec has also developed patented processes for manufacturing ceramic tiles from different waste forms. Some of this work has been supported by DOE SBIR and Ben Franklin Grants.

The following is a summary of several of our industrial waste recycling commercialization projects.

Ormet Spent Pot Liner Recycling Project

Vortec has negotiated a sales & licensing agreement with Ormet Primary Aluminum for the construction of a CMS™ based spent potliner vitrification process at Ormet's Hannibal, Ohio, aluminum reduction plant. Spent potliner (SPL) is generated during the smelter of aluminum using the Hall-Heroult Process, which is currently used in all primary aluminum reduction operations. In removing the liner from the pot, the insulating bricks and pot liner itself are often mixed or co-mingled, resulting in a hazardous waste which consists of a mixture of the carbon based liner, barrier brick, and the insulation brick. Carbon liners can be anthracite or graphite based. The CMS™ technology has the advantage, relative to conventional technologies, of being able to process the entire mixture, oxidizing the carbon in the liner, and rapidly melting the refractory (brick) material to produce an oxidized glass frit. The ORMET system has the capacity to process approximately 50 tons/day of spent potliner producing a glass frit which will be sold to a glass manufacturer for use as an additive to other glass making ingredients. The total investment in the process is approximately $8 million, inclusive of engineering and design, equipment for all major and support systems, site modifications, construction, and start-up operations. Total processing cost is estimated to be about $80/ton. Ormet expects to sell the glass frit for $10 to $30/ton. It currently costs Ormet approximately $350/ton to dispose of their potliner. Therefore, a net savings on the order of $290/ton will be realized through vitrification with the CMS™ technology. This provides a payback on capital investment of approximately 3 years.

<u>Other Industrial Waste Recycling Projects</u>

Vortec is also planning the construction of several recycling facilities for processing combinations of spent pot liner waste and boiler flyash in the Unites States. One of the plants we are targeting will process a combination of spent potliners and industrial boiler ash. The estimated costs for greenfield plant which will process 52,500 ton/yr of waste is approximately $10.0 million. A proforma for the operating and maintenance costs as well as revenue generation and capital payback is provided in Table 4.3-1.

The proforma is based on the processing of spent pot lines with a tipping fee of $200/ton and boiler flyash with a tipping fee of $20/ton. The end products to be manufactured include frits for ceramic tile manufacturing (selling price $20/ton) and abrasives (selling price $200/ton). The net after tax profits for the project is expected to be about $3 million/yr. The project which assumes an equity investment of $3 million in investment capital has an investment payback of about 2 years. The total capital payback period (excluding depreciation) is approximately 2.4 years. The contribution margin ratio is an attractive 77%.

Vortec has formed a strategic alliance with Welko, a major ceramic tile equipment manufacturer, to provide the technology for manufacturing ceramic tiles from various industrial waste materials. To date, our technology development with Welko has focused on the production of engineered frits, using the Vortec Cyclone Melting System (CMS™), followed by the pressing and firing of the tiles using existing tile manufacturing equipment.

Table 4.3-1 Proforma for a 52,500 ton/yr SPL and Ash Recycling Plant

			SPL-Ash- Frit Plant			
	Units	*Cost Factor*		*$ per Year*	*$ per sq ft*	*$ per ton*
Investment Cost Factors						
Annual Waste Utilization	*ton/yr*	*52,500*				
Product Yield	*%*	*0.77*				
Annual Tile Production	*sq ft/yr*	*20,250,000*				
Annual Glass Production	*ton /yr*	*40,500*				
Energy Utilization	*MMBtu/ton*	*2*				
Gas Cost	*$/MM Btu*	*3*				
Electric Utilization	*kWh/ton*	*300*				
Electric Costs	*$/kWh*	*0.065*				
Operating Days	*Days*	*350*				
Daily Glass Porduction	*ton/day*	*116*				
Tile Production Factor	*sq ft tile/ton glass*	*500*		*Depreciation*		
Total Capital Costs	*Plant Life-Yrs*	*15*	***$10,000,000***	***$666,667***	***0.033***	***$16.46***
Direct Operating Cost/Year						
Labor	*$/hr*	*12*	*16*	*$384,000*	*0.019*	*$9.48*
Overhead			*35%*	*$115,200*	*0.006*	*$2.84*
Materials					*0.000*	*$0.00*
Fuel				*$243,000*	*0.012*	*$6.00*
Additve Raw Materials	*$/ton*	*25*	*10.00%*	*$101,250*	*0.005*	*$2.50*
Feedstocks		*0*	*0.9*	*$0*	*0.000*	*$0.00*
Electrical Power				*$789,750*	*0.039*	*$19.50*
Maintenence			*0.04*	*$400,000*	*0.020*	*$9.88*
Analytical				*$100,000*	*0.005*	*$2.47*
Glaze Cost	*$/sq ft*	*0*		*$0*	*0.000*	*$0.00*
Shipping Costs	*FOB Plant*	*0*		*$0*	*0.000*	*$0.00*
Packaging	*$/ton*	*0*	*100%*	*$0*	*0.000*	*$0.00*
Total Direct Operating Cost				***$2,133,200***	***0.105***	***$52.67***
G&A Expense						
Management				*$100,000*	*0.005*	*$2.47*
Engineering/Technical Support				*$100,000*	*0.005*	*$2.47*
Sales & Marketing				*$50,000*	*0.002*	*$1.23*
Misc. (Ins, Rent, Legal, Utilities)				*$80,000*	*0.004*	*$1.98*
Total G&A Expense				***$330,000***	***0.016***	***$8.15***
Contingency			*0.05*	*$123,160*	*0.006*	*$3.04*
Total Annualized Cost				***$3,253,027***	***0.161***	***$80.32***
Revenues						
Waste Processing Fees						
Waste 1	*$/ton*	*200*	*60%*	*$6,300,000*	*0.311*	*$155.56*
Waste 2	*$/ton*		*0%*	*$0*	*0.000*	*$0.00*
Waste 3	*$/ton*	*20*	*40%*	*$420,000*	*0.021*	*$10.37*
Product Sales						
Product 1	*$/ton*	*20*	*75%*	*$607,500*	*0.030*	*$15.00*
Product 2	*$/ton*	*200*	*25%*	*$2,025,000*	*0.100*	*$50.00*
Product 3	*$/ton*		*0%*	*$0*	*0.000*	*$0.00*
Subtotal- Revenues				***$9,352,500***	***0.462***	***$230.93***
Income Before Taxes (Loss)				***$6,099,473***	***0.301***	***$150.60***
Cost of Money			*10%*	***$700,000***	***0.035***	***$17.28***
Taxes (Federal & State)			*35%*	***$1,889,816***	***0.093***	***$46.66***
Net Profit (After Taxes)				***$3,509,658***	***0.173***	***$86.66***
Investment Capital	***3,000,000***					
Debt Capital	***$7,000,000***					
Capital Payback Period (yrs)	*w/ Depreciation*			**2.85**		
Capital Payback Period (yrs)	*w/o Depreciation*			**2.39**		
Investment Payback ($/yr,%,Yr)	***1,509,153***		*43%*	**1.99**		
Contribution Margin Ratio				**77.2%**		

The pressing and firing steps use proprietary tile forming and glazing technology developed by Welko. The technology base for producing bonded tiles from glass/ceramic frits is currently ready for implementation. A commercial exposition of the Vortec/Welko tiles manufactured from recycled waste is planned in October 1995 in Rimini, Italy.

The waste materials we have targeted for our first recycling plants will include: coal-fired boiler flyash, spent pot liners from aluminum smelting operations and metal plating and/or paint sludges. The tile products we can produce (called EKOTILE) contain more than 90% of the VOR-TILE™ frit. The initial product introduction will be high wear resistant floor tiles which feature technical specifications equivalent to or better than 'granites'. The ceramic blanks can be decorated and glazed using the most advanced existing production technology, thereby ensuring the widest possible market acceptance. Moreover this material, with a degree of hardness of 500 kg/cm^2 and 1% water absorption, will place it among the top single fired floor tiles offered in the market today.

Spent pot liners are an excellent feedstock for the VOR-TILE process because of the nature of the compounds in the waste material make an excellent frit for bonded ceramic tiles. These recycling plants will be owned and operated by VOR-TILE™, a subsidiary of Vortec Corporation. We have a number of options where we can site these plants, and will be performing some feasibility studies before we finalize the plant locations. For at least one feasibility study, we will be looking into siting a facility in western Virginia near Blacksburg. This location is centrally located among several major spent pot liner sources.

We have received an informal commitment from a major chemical manufacturer to provide land and utilities for a processing plant on the property of their Virginia facility. They are interested in providing their boiler ash as one of the feedstocks for the recycling plant.

We currently have a letter of intent from on major aluminum smelter to process 7,000 MT/yr of spent pot liners from their SC plant and an additional 10,000 MT/yr of spent pot liners from their Maryland plant. An additional 14,000 MT/yr is available from their other plants in Quebec, Canada; however, we will most likely examine the construction of a more northern facility to process the Canadian waste materials.

We also have been in contact with another aluminum smelter, which has 25,000 MT/yr of spent pot liners generated their smelting plants in the Eastern United States. With the addition of the glass formers (admix) to the spent pot liners, the total glass product manufactured is approximately twice the spent pot liners utilized. Therefore the production of engineered feedstock from spent pot liners for ceramic tile manufacturing in the Eastern U.S. could amount to more than 100,000 MT/yr. An equivalent capacity would be available in the Pacific Northwest.

The cost of raw materials for existing clay-based ceramic tile manufacturing represents from 15% to 35% of the cost of manufacturing. The use of waste materials as a feedstock has the potential for not just reducing the raw material costs but providing a source of income in terms of tipping fees for some wastes. Manufacturing cost savings of 25% are estimated for a CMS™ based ceramic tile manufacturing process relative to existing clay-based manufacturing operations. Coal-fired boiler flyash represents a unique opportunity for this process application. First, the oxide constituents of coal ash are essentially the same as many commercial glasses. Second, there are essentially unlimited supplies of the feedstock. Third, it is possible to receive a tipping fee for the feedstock. fourth, the ash can serve as an energy source for the process, and fifth, the recycling of residual and industrial waste materials will alleviate a substantial number of environmental problems associated with landfilling.

Vortec is currently looking for investment capital to allow VOR-TILE™ to construct several waste recycling operations in the United States with processing capacities of nominally 50,000 ton/yr. This size plant will produce approximately 40,000 ton/yr of frits for tile manufacturing and other applications. This frit production is sufficient to manufacture about 20 million ft^2 of finished tile products. Savings in tile manufacturing costs could amount to about $2 million/yr. Therefore, there is strong interest from the tile industry in project being proposed.

Vortec has prepared a proprietary commercialization/business plan for the construction and operation of glass/ceramic tile manufacturing plants using coal-fired boiler flyash and/or other waste as the feedstock. The plan includes discussions on the present situation with respect to market environment, products and services, pricing and profitability, customers, distribution, and management; VOR-TILE™ product, service, and management descriptions; market analysis including market definition and competition; marketing and manufacturing strategies; and financial projections.

4.3.2.2 Radioactive and Hazardous Waste Remediation

The U.S. Department of Energy (DOE) has selected the gaseous diffusion plant located in Paducah, Kentucky as the commercial demonstration site for the Vortec Corporation advanced vitrification process. The waste remediation plant will incorporate the use of the Vortec patented glass melting system known as the CMS™ for the vitrification process unit. Vitrification is being used for the processing of radioactive solid waste at the site because it produces a glass product which is chemically stable for thousands of years. The Vortec CMS™ is unique in that it allows for the simultaneous processing of organic, heavy metal, and radionuclide containing waste materials.

In addition to its flexibility in processing a wide variety of waste forms, other advantages of the CMS™ process include: (1) its ability to process polychlorinated biphenyl (PCB) contaminated wastes; (2) the low capital and operating/maintenance cost of the process; and (3) the advanced health, safety and environmental protection features included in the overall process design.

DOE's Morgantown Energy Technology Center (METC) of West Virginia is the project administrator. The contract is sponsored by the DOE Office of Technology Development (EM-50).

According to the Paducah Site Manager, the Paducah Gaseous Diffusion Plant (PGDP) has approximately 15,300,000 pounds of hazardous/radioactive (mixed), PCB/radioactive and low-level waste streams in storage. The majority of these waste streams are soil, concrete, and other materials amenable to the Vortec vitrification process. In addition, a large volume of contaminated soil is still in the ground which has been identified as part of the ongoing Environmental Restoration program. This waste may also be amenable to vitrification. Current waste storage facilities at PGDP are at or near capacity. Since PGDP does not have on-site treatment or disposal facilities to accept this waste, additional high cost storage facilities would have to be constructed. If the use of the vitrification process is demonstrated to destroy the TSCA (PCB) wastes and chemically stabilizes the radioactive wastes and RCRA wastes, it will significantly reduce costs and result in a material which will meet disposal facility waste acceptance criteria.

While at PGDP, the unit could be utilized to perform vitrification demonstrations on wastes stored at other DOE facilities, such as Oak Ridge, Tennessee and Portsmouth, Ohio. Upon completion of waste processing at PGDP, the unit could be dismantled and moved to one of these other facilities for full scale vitrification of their waste.

A 30-day, on-site demonstration will process 36 ton/day of drummed soil contaminated with hazardous and radioactive constituents. Operation of the plant will be managed by Vortec Remediation Services, Inc. and the construction phase of the program is scheduled to begin the first quarter of 1996. All subsystems are designed to be transportable and modular which will minimize the installation time and also facilitate decommissioning and removal from the site after its mission has been achieved.

The primary advantages of the CMS™ technology relative to competing technologies, primarily joule-heated melters and plasma arc melters, are its ability to cost effectively vitrify large volumes of waste and efficiently destruct hazardous organic constituents in the waste. Additionally, the CMS™ technology can produce a homogeneous glass product from wastes containing higher concentrations of iron and other metals which tend to form immiscible layers in pool type melters. Processing costs with the CMS™ technology are expected to be in the range from $50 to $100 per barrel compared to $500 to $1000 per barrel for competing technologies.

Paducah has a mixture of LLW, TSCA/LLW and RCRA/LLW wastes in its current inventory. The current inventory of wastes are as follows:

•	Low level waste inventory	ca. 12.0 million lbs
•	PCB/low level waste inventory	ca. 8.0 million lbs
•	RCRA low level	ca. 1.0 million lbs

In addition to the current waste inventory, it is projected that over the next 5 years, Paducah will generate the following additional wastes:

•	Low level waste generation	ca. 48,000 ft^3
•	PCB/Radioactive waste generation	ca. 108,000 ft^3
•	RCRA/Radioactive waste generation	ca 48,000 ft^3

In March of 1995, DOE-ORNL committed to support of the Vortec Vitrification Demonstration Plant and further suggested that the soil inventory stored at Paducah's

Gaseous Diffusion Plant be the material processed by the demonstration. There are three major waste categories which will be evaluated under the demonstration program. These major waste categories will include:

1.	Low Level Wastes	ca. 8.0 million lbs or 135,000 ft^3,
2.	PCB/Radioactive Wastes	ca. 6.3 million lbs or 135,000 ft^3,
3.	RCRA/Radioactive (Mixed)	ca. 1.0 million lbs or 30,000 ft^3.

Table 4.3-2 presents a listing of eight major waste streams stored at the Paducah site which can potentially be processed via the Vortec vitrification system. These waste streams represent approximately 80% of the soil type waste available at the site. In addition, the approximately one million pounds of RCRA wastes can also be potentially processed by blending with the contaminated soils.

Implementation of the Vortec vitrification technology at PGDP will solve a number of the near term and longer range treatment and disposal problems for DOE. The Paducah wastes present disposal problems because a large portion of the wastes are combinations of LLW, TSCA and RCRA waste forms. Because the Vortec Vitrification process can process and treat combinations of waste forms, it precludes the necessity of using a series of treatment technologies to arrive at a final waste form which can be permanently entombed. By effectively destroying the TSCA contaminants and chemically stabilizing the RCRA and Radionuclide components in non-leachable glass products, a large portion of final waste forms could be entombed on-site at a recently permitted landfill. On-site storage will be suitable for wastes with activity levels less than 30 pCi/gm. Treatment on-site will provide major cost benefits to the site, mitigate problems associated with over-the-road transportation and out-of-state disposal, and will widen the options for terminal disposal of the final waste form. The major problems at Paducah are the LLW and the TSCA wastes which constitute the majority of the current waste inventory. Projections also indicate that LLW and TSCA waste will be the major waste forms generated over the next five years.

Table 4.3-2
Candidate Low Level Waste Streams from the Paducah Inventory

ITEM	LLW WASTE DESCRIPTION	QUANTITY (LBS.)
	LLW WITHOUT PCB'S	
1	DIRT (INCLUDING ROCK, DIRT AND CONCRETE)	1,640,882
2	DRILLING MUD	1,255,000
3	SOIL	5,660,579
	SUBTOTAL	**7,556,461**
	LLW WITH PCB'S	
4	DEBRIS (INCLUDING SPILL DEBRIS)	1,071,087
5	CONCRETE	1,451,137
6	ROCK AND SOIL	1,273,785
7	SEDIMENT	774,065
8	SOIL	594,657
	SUBTOTAL	**5,164,731**

Near Term Benefits to Paducah

PGDP currently faces difficult challenges with regard to the disposal of its current inventory of LLW, TSCA/LLW and RCRA/LLW waste forms. There are currently about 40,000 drums of these waste materials stored on-site. The Vortec vitrification process has the potential of treating 80% (32,000 drums) of these waste materials so they can be permanently entombed. Therefore, the current demonstration program can go a long way to solving its current waste disposal needs. The processing capacity of the Vortec vitrification demonstration plant is expected to be in the range of 25-50 ton/day of dried feedstock delivered to the CMS™. This translates to 36-72 ton/day of as received, wet materials. At an average drum weight of 450 lbs per drum, the drum processing capacity will be in the range of 160 to 320 drums per day. Current plans are to have the plant permitted at the 72 ton/day (320 drum/day) processing capacity. In the thirty days of operation of the demonstration plant, it is estimated that the plant will process approximately 240 drums per day or 7,200 drums over the 30 day demonstration. Based on a defrayed cost savings of nominally $450 to $900 per drum (in relation to the use of existing technologies for remediation/disposal), the estimated cost benefit to the Paducah Operations could be in the range of about $3.6 million to $7.2 million in treatment/disposal costs.

In addition to the significant cost savings, other important near term benefits will accrue to PDGP as well as the state of Kentucky. For example, implementation of the technology will be to provide a means of establishing waste disposal equity between the states of Ohio, Tennessee and Kentucky. Because Paducah currently does not have an on-site treatment process for theses wastes, they currently must be stored or disposed of off-site.

Potential Long Term Benefits to Paducah

The long range benefits to Paducah will stem from the processing of the current waste inventory as well as the waste inventory to be generated over the next 5 years. The annual waste generation is expected to range between approximately 4,000 and 9,000 barrels per year.

By extension of the demonstration program, it should be possible to treat/dispose of the current inventory of 32,000 drums targeted for processing with the CMS™ in approximately 133 days. The projected operating and maintenance cost of the CMS™ to be constructed at Paducah is in the range of $65 to $100/ton. At an estimated cost savings of approximately $300 to $800/ton (assuming final on-site landfilling at $100/ton), the total estimated cost savings in treatment/disposal would be in the range of $9.6 - $25.6 million for the existing waste inventory.

Using the CMS™ to process 80% of the additional 28,000 barrels of wastes to be generated on site over the next 5 years would result in incremental cost savings in the range of $6.6 - $17.6 million. The total treatment/disposal cost savings for Paducah through the year 2000 is estimated to be in the range of $16.2 - $46.2 million. This represents a significant cost savings in remediation and disposal costs for the Paducah operations.

Relevance to Other DOE Remediation Programs

In addition to the waste to be processed at Paducah, the Vortec Melting System has direct application to other DOE remediation programs. The DOE has approximately 4,000 contaminated sites covering tens of thousands of acres replete with contaminated hazardous or radioactive waste, soil or structures. It has more than 250,000 cubic meters of transuranic (TRU) waste and millions of cubic meters of low level radioactive waste (LLW) as well as substantial quantities of mixed RCRA/LLW and TSCA/LLW wastes. In addition, the DOE is responsible for thousands of facilities awaiting decontamination, decommissioning, and dismantling. Consequently, the Office of Environmental

Management (EM) faces major technical, planning and institutional challenges in meeting its expanding environmental responsibilities while controlling cost growth.

The mixed wastes represent a significant challenge for DOE. A significant portion of these wastes (ca.70%-80%) can be effectively processed using the transportable vitrification system configuration to be constructed for the Paducah demonstration program. A summary of the mixed waste volumes for DOE sites is summarized in Table 4.3-3. As seen from the data presented in the table, the Fernald, INEL, Oak Ridge, Portsmouth, Rocky Flats and Savannah River sites each have more than 1000 cubic meter inventories of mixed wastes. The total mixed waste inventory is about 70,000 cubic meters, and the annual generation is nearly 8,000 cubic meters per year. Vortec has not identified similar summary tables of low level wastes and TSCA/low-level wastes and DOE site. However, it is projected that the LLW and TSCA/LLW waste streams inventories are in the millions of cubic meters.

Vortec has prepared a proprietary business plan for commercialization of the technology for remediation of low level radioactive contaminant containing wastes (LLW). The plan includes identification of the market; a market environment analysis; marketing and sales plan; discussion of the competition; human resources plan; and financial information including cash flow analyses.

4.3.2.3 Commercial Glass Melting and Waste Glass Recycling

Vortec Corporation has established strategic alliances with several major glass manufacturers to commercialize the CMS™ technology for container glass, fiber glass and specialty glass manufacturing.

Post-consumer container glass waste recycling, industrial fiberglass manufacturing waste glass recycling, and basic glass manufacturing in the glass industry are other promising markets being pursued by Vortec for the CMS™ technology. The primary technical advantage of the CMS™ technology relative to conventional melting technologies in the recycling of waste glass is its ability to oxidize organic and metallic contaminants in the waste material. Post consumer container glass contains paper and foil labels that are difficult to remove to the extent necessary to recycle the glass into some conventional

Table 4.3-3
Mixed Waste Volume Information for the DOE Sites

	Current Inventory (m^3)(a)	**Generation Rate (m^3/yr)**
Ames Laboratory	0.10	0.10
Argonne National Laboratory-East	0.00	36.24
Argonne National Laboratory-West	9.05	0.95
Bettis Atomic Power Laboratory	6.56	0.35
Brookhaven National Laboratory	15.83	10.65
Colonie Interim Storage Site	38.77	0.00
Fermi National Accelerator Laboratory	2.10	0.00
Fernald	3928.70	16.80
Grand Junction Project Office	0.06	0.09
Hanford Site	2285.98	144.20
Idaho National Engineering Laboratory	26716.26	2758.51
IT Research Institute	0.20	1.00
K-25 Site	7035.50	112.00
Kansas City Plant	3.73	2.47
Knolls Atomic Power Laboratory	0.00	0.45
Lawrence Berkeley Laboratory	3.80	0.02
Lawrence Livermore National Laboratory	134.50	102.00
Los Alamos National Laboratory	323.93	85.34
Mound Facility	40.60	2.00
Nevada Test Site	0.00	48.70
Oak Ridge National Laboratory	1268.16	16.28
Paducah Gaseous Diffusion Plant	602.96	30.62
Pantex Plant	95.47	5.30
Portsmouth Gaseous Diffusion Plant	4900.57	311.59
Princeton Plasma Physics Laboratory	0.02	0.01
Rocky Flats Plant	3438.25	423.20
Sandia National Laboratory Albuquerque	0.00	166.80
Sandia National Laboratory Livermore	0.14	0.42
Santa Susana Field Laboratory (ETEC)	3.32	0.00
Savannah River Site	9038.51	1610.65
Weldon Spring Site Remedial Actions	56.05	0.00
West Valley	20.00	1.00
Y-12	9972.30	1801.02
Totals	69941.42	7688.71

(a) Note the number of significant figures shown for consistency in calculation exceeds the accuracy of the data.

melting processes. Waste fiberglass contains an organic binder or sizing which if introduced into conventional pool type melters robs oxygen from glass forming ingredients, particularly SiO_2, reducing the glass, and thus changing its properties and resulting in the formation of stones. The stones adversely impact the performance of the fiberizing operations.

The primary advantage of the CMS™ technology with respect to primary glass manufacturing is its high thermal efficiency resulting from the more efficient suspension heating of the feedstock. Typical heat rates for an oxy-fuel fired CMS™ are 3, 3, and 5 MM Btu per ton of glass for container, insulation fiberglass and reinforcement fiberglass melting, respectively. In comparison, typical heat rates are 4, 4.5, and 12 for conventional oxy-fuel containers, insulation fiberglass and reinforcement fiberglass melting furnaces, respectively.

Summaries of the estimated potential energy savings and waste reduction savings associated with implementation of the CMS™ technology into the reinforcement fiberglass, container glass, and insulation fiberglass segments of the glass industry based on 1994 glass production levels are presented in Tables 4.3-4 and 4.3-5. Total cost savings potential for these segments based on 1994 production levels and projected 1999 and 2010 production levels are summarized in Table 4.3-6. Commercialization of the technology in the glass industry provides the potential for melting energy savings of more than 20 trillion Btu/yr (>30%), energy cost savings of over $70 million/yr, and total manufacturing cost savings of over $300 million/yr.

Table 4.3-4
Energy Savings Potential Associated With Commercialization of CMS™ Technology in the Glass Industry

	Reinforcement Fiberglass	Container Glass	Insulation Fiberglass	Total
Annual Production of Finished Glass Product (tons/year)	848,000 [4]	11,800,000 [1]	1,690,000 [1]	14,338,000
Furnace Pull (tons/year)	1,130,000	11,800,000	1,797,872	14,727,872
Conventional Furnace Heat Rate (MMBtu/ton of pull)	12.00 [4]	4.00	4.40	
Avg. CMS Heat Rate (MMBtu/ton pull)	4.84	3.10	3.10	
Conventional Furnace Energy Utilization (MMBtu/yr)	13,560,000	47,200,000	7,910,638	68,670,638
CMS Energy Utilization (MMBtu/yr)	5,466,375	36,580,000	5,573,404	47,619,779
Incremental Fuel Energy Savings (MMBtu/Ton)	7.16	0.90	1.30	
Incremental Fuel Energy Savings (MMBtu/Year)	8,093,625	10,620,000	2,337,234	21,050,859
Incremental Percentage Fuel Energy Savings	60%	23%	30%	
Conventional Furnace Fuel Energy Cost To Glass Industry ($/yr) [3]	$47,460,000	$165,200,000	$27,687,234	$240,347,234
CMS Fuel Energy Cost To Glass Industry ($/yr) [3]	$19,132,313	$128,030,000	$19,506,915	$166,669,227
Fuel Energy Cost Savings, ($/yr)	$28,327,688	$37,170,000	$8,180,319	$73,678,007
Oxygen Electrical Energy Requirement (kW-hr/ton O2)	260	260	260	
Oxygen Thermal Energy Requirement (MMBtu/ton O2) [2]	2.73	2.73	2.73	
Conventional Furnace Oxygen Utilization (tons O2/yr)	0.00	4,777,464	800,695	5,578,158
CMS Oxygen Utilization (tons O2/yr)	553,293	3,702,534	564,126	4,819,953
Oxygen Savings (tons O2/year)	-553,293 [6]	1,074,929	236,569	758,206
Conventional Furnace Oxygen Gen: Thermal Energy (MMBtu/yr)	0	13,042,476	2,185,896	15,228,372
CMS Oxygen Generation Thermal Energy (MMBtu/yr)	1,510,489	10,107,919	1,540,063	13,158,471
Oxygen Thermal Energy Savings (MMBtu/year)	-1,510,489 [6]	2,934,557	645,833	2,069,901
Oxygen Thermal Energy Savings (MMBtu/ton)	-1.34 [6]	0.25	0.36	
Conventional Furnace Oxygen Cost to Glass Industry ($/yr) [5]	$0	$167,211,231	$28,024,313	$195,235,544
CMS Oxygen Cost to Glass Industry ($/yr) [5]	$19,365,239	$129,588,704	$19,744,402	$168,698,345
Oxygen Savings to Glass Industry ($/yr)	($19,365,239)	$37,622,527	$8,279,911	$26,537,198
Total Net Energy Savings (MMBtu/ton)	5.83	1.15	1.66	
% Total Energy Savings	49%	29%	38%	
Net Energy Savings (MMBtu/year)	6,583,136	13,554,557	2,983,067	23,120,761

[1] Advanced Glass Melter Technology Assessment, Charles River Associates, Assuming Flat Market From 1989 to 1994
[2] Electrical to 02 Thermal Energy Conversion of 10,500 Btu/kW-hr
[3] Gas Cost of $3.50 per MMBtu
[4] Vetrotex CertainTeed, Personal Communication
[5] 02 Cost of $35/ton
[6] Negative Savings Because Reinforcement Fiberglass Segment Does Not Currently Use Oxy-Fuel Fired Furnaces

Table 4.3-5
Waste Reduction Potential Associated With Commercialization of CMS™ Technology in the Glass Industry

	Reinforcement Fiberglass	Container Glass	Insulation Fiberglass	Total
Annual Production of Finished Glass Product (tons/year)	848,000	11,800,000	1,690,000	14,338,000
Furnace Pull (tons/year)	1,130,667	11,800,000	1,797,872	14,728,539
Waste glass Recycled (tons/year)	282,667	299,645	71,915	654,227
Feedstock Savings (tons/year)	354,276	0	384,251	738,527
Cost Savings of Feedstock ($/year)	$35,427,556	$23,971,631	$30,740,092	$90,139,279

Table 4.3-6
Summary of Potential Cost Savings Associated With Commercialization of the CMS™ Technology in the Glass Industry

	Year 1994			
	Reinforcement Fiberglass	Container Glass	Insulation Fiberglass	Total
Annual Production of Finished Glass Product (tons/year)	848,000	11,800,000	1,690,000	14,338,000
Furnace Pull (tons/year)	1,130,667	11,800,000	1,797,872	14,728,539
Fuel Energy	$28,327,688	$37,170,000	$8,180,319	$73,678,007
Oxygen	($19,365,239)	$37,622,527	$8,279,911	$26,537,199
Feedstock	$35,427,556	$23,971,631	$30,740,092	$90,139,279
Maintance	$9,045,333	$94,400,000	$14,382,979	$117,828,312
Total	$53,435,338	$193,164,158	$61,583,301	$308,182,797

	Year 1999			
	Reinforcement Fiberglass	Container Glass	Insulation Fiberglass	Total
Annual Production of Finished Glass Product (tons/year)	973,000	11,800,000	1,690,000	14,463,000
Furnace Pull (tons/year)	1,297,333	11,800,000	1,797,872	14,895,206
Fuel Energy	$32,532,544	$37,170,000	$8,180,319	$77,882,863
Oxygen	($22,239,743)	$37,622,527	$8,279,911	$23,662,695
Feedstock	$40,649,778	$23,971,631	$30,740,092	$95,361,501
Maintance	$10,378,667	$94,400,000	$14,382,979	$119,161,645
Total	$61,321,246	$193,164,158	$61,583,301	$316,068,704

	Year 2010			
	Reinforcement Fiberglass	Container Glass	Insulation Fiberglass	Total
Annual Production of Finished Glass Product (tons/year)	1,250,000	11,800,000	1,690,000	14,740,000
Furnace Pull (tons/year)	1,666,667	11,800,000	1,797,872	15,264,539
Fuel Energy	$41,781,233	$37,170,000	$8,180,319	$87,131,552
Oxygen	($28,562,288)	$37,622,527	$8,279,911	$17,340,150
Feedstock	$52,222,222	$23,971,631	$30,740,092	$106,933,945
Maintance	$13,333,333	$94,400,000	$14,382,979	$122,116,312
Total	$78,774,500	$193,164,158	$61,583,301	$333,521,959

5.0 SUMMARY AND CONCLUSIONS

Vortec and DOE/PETC have completed a three phase research and development program which has resulted in the commercialization of a process heater, capable of being fueled by pulverized coal, natural gas, and other solid, gaseous, or liquid fuels, for the vitrification of industrial wastes. During Phase III, twenty-three tests ranging in duration from 3 hours to the final demonstration test of 105 hours were performed under the program on a nominal 15 ton/day advanced combustion and melting system (CMS™) which was constructed during Phase II. An additional 53 major tests, sponsored by DOE and EPA SBIR programs and potential industry users, were performed with the system. The tests have demonstrated the technical feasibility of vitrifying a wide variety of industrial wastes in the CMS™, including coal-fired boiler flyash, municipal solid waste incinerator ash, sewage sludge incinerator ash, spent aluminum potliner, post-consumer glass, and waste fiberglass.

As a result of these research and development activities, Vortec has identified the most promising markets for the CMS™ technology as industrial solid waste recycling into value-added products, remediation of hazardous and radioactive wastes, and commercial glass melting and waste glass recycling. The primary advantages of the CMS™ technology relative to current and competing technologies in these markets are its ability to rapidly melt inorganic constituents in feedstock using a variety of fuels, efficiently oxidize organic constituents which could otherwise be hazardous pollutants, and reduce NO_x emissions. These advantages are provided by the efficient heating of feedstock in suspension with the products of combustion and excess air/oxygen in the process. As a result, the high temperature components comprising the process are smaller in physical size than conventional melting components and thus have lower structural heat losses. This results in higher thermal efficiencies and lower capital and operating costs. The CMS™ technology can produce a homogenous glass product from waste and other glass forming materials with a total glass residence time on the order of 1 hour compared to conventional melter residence times of 24 hours and greater. NO_x emissions of less than 4.5 lb/ton are anticipated for commercial units compared to 8 to 16 lb/ton for conventional fossil fuel fired melting systems.

Vortec has negotiated a sales & licensing agreement with Ormet Primary Aluminum for the construction of a CMS™ based spent potliner vitrification process at Ormet's Hannibal, Ohio, aluminum reduction plant. The CMS™ technology has the advantage, relative to conventional technologies, of being able to process the a mixture of the carbon liner and brick material to produce an oxidized glass frit. The ORMET system will process approximately 34 tons/day of spent potliner producing a glass frit which will be sold to a glass manufacturer for use as an additive to other glass making ingredients. The payback on capital investment in the process is expected to be less than 3 years.

Vortec currently has a contract with DOE/METC for the construction and operation of a 36 ton/day CMS™ field demonstration process for remediation of soils and other wastes containing hazardous and radioactive constituents at DOE's Paducah Gaseous Diffusion Plant in Paducah, Kentucky. The primary advantages of the CMS™ technology relative to competing technologies, primarily joule-heated melters and plasma arc melters, are its ability to cost effectively vitrify large volumes of waste (several hundred tons/day with a single unit) and efficiently destruct hazardous organic constituents in the waste. Processing costs with the CMS™ technology are expected to be in the range from $50 to $100 per barrel compared to $500 to $1000 per barrel for competing technologies.

Vortec has also prepared a commercialization/business plan for the construction and operation of glass/ceramic tile manufacturing plants using coal-fired boiler flyash and/or other wastes as the feedstock. The cost of raw materials for existing clay-based ceramic tile manufacturing represents from 15% to 35% of the cost of manufacturing. The use of waste materials as a feedstock has the potential for not just reducing the raw material costs but providing a source of income in terms of tipping fees for some wastes. Manufacturing cost savings of 25% are estimated for a CMS™ based ceramic tile manufacturing process relative to existing clay-based manufacturing operations.

The primary technical advantage of the CMS™ technology relative to conventional melting technologies in the recycling of waste glass is its ability to oxidize organic and metallic contaminants in the waste material. The primary advantage of the CMS™ technology with respect to primary glass manufacturing is its high thermal efficiency resulting from the more efficient suspension heating of the feedstock. Typical heat rates for an oxy-fuel fired CMS™ are 3, 3, and 5 million Btu/ton of glass for container, insulation fiberglass, and reinforcement fiberglass, respectively. In comparison, typical heat rates are 4, 4.5, and 12 for conventional container, insulation fiberglass, and reinforcement fiberglass furnaces, respectively. Commercialization of the technology in the glass industry provides the potential for melting energy savings of more than 20 trillion Btu/yr (>30%), energy cost savings of over $70 million/yr, and total manufacturing cost savings of over $300 million/yr. Strategic alliances with several major glass manufacturers are being developed to commercialize the CMS™ technology for commercial glass melting applications.

Other waste vitrification applications for the CMS™ technology being pursued by Vortec include municipal solid waste and sewage sludge incinerator ash, automobile shredder residue gasifier ash, and electric arc furnace (EAF) dust. The projected processing cost of less than $50 to $100/ton using the CMS™ technology is competitive with current landfill disposal costs. The production of value added glass products from these materials increases the economic incentive for commercial implementation of the technology. Potential markets for the glass produced from the vitrification of these waste materials include asphalt shingle granules; admixes for the manufacture of bricks, paving asphalt, and other construction materials; and glass/ceramic tiles.