Energy & Environmental Research Center

CATALYTIC FABRIC FILTRATION FOR SIMULTANEOUS NO_x AND PARTICULATE CONTROL

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TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	ii
LIST OF TABLES	ii
1.0 INTRODUCTION	1
2.0 SCOPE OF WORK	2
3.0 GOALS AND OBJECTIVES	3
4.0 ACCOMPLISHMENTS	4
4.1 Subtask 3.1 – Fundamental Testing	4
4.2 Subtask 3.2 – Process Testing/Reverse-Gas System	8
4.3 Subtask 3.3 – Process Testing/Pulse-Jet System	11
4.4 Subtask 3.4 – Fabric Durability Testing/Pulse-Jet System	11
4.5 Task 4 – Conceptual Design and Economic Evaluation	23
5.0 KEY PERSONNEL STAFFING REPORT	23
6.0 REFERENCES	24

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Schematic of bench-scale reactor system	4
2	NO _x removal and ammonia slip versus ammonia-to-NO _x molar ratio for bench-scale fabric screening tests	9
3	NO _x removal and ammonia slip versus ammonia-to-NO _x molar ratio for coal- and oil-fired test periods.	10
4	Steam plant baghouse mean temperature versus run time	12
5	Steam plant baghouse face velocity versus run time	12
6	Steam plant baghouse differential pressure versus run time	13
7	Mass emissions and pressure drop as a function of time for the steam plant baghouse, August 4, 1993	19
8	Mass emissions and pressure drop as a function of time for the steam plant baghouse, September 10, 1993	20
9	Mass emissions and pressure drop as a function of time for the steam plant baghouse, September 29, 1993	21
10	A summary of multicyclone data for ash collected in the steam plant baghouse	22

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Bench-Scale Catalyst Deactivation Test Results	6
2	Coal Ash Analysis for Catalyst Deactivation Tests	7
3	XRF Analysis of Steam Plant Baghouse Hopper Ash, August and September 1993	14
4	Steam Plant Particulate Sampling Data	15
5	Steam Plant Multicyclone Data	16
6	Planned Versus Actual Work Hours for Key Project Personnel Through September 1993	23

CATALYTIC FABRIC FILTRATION FOR SIMULTANEOUS NO_x AND PARTICULATE CONTROL

1.0 INTRODUCTION

The University of North Dakota Energy & Environmental Research Center (EERC), Owens-Corning Fiberglas Corporation (OCF), and Raytheon Engineers & Constructors (RE&C), are conducting research to develop a catalytic fabric filter (CFF) for simultaneous NO_x and particulate control. Funding for the project is being provided by the U.S. Department of Energy/Pittsburgh Energy Technology Center (DOE/PETC), Consolidated Edison Company of New York Inc. (Con Edison), and the Empire State Electric Energy Research Corporation (ESEERCO). OCF is providing catalyst-coated bags, fabric samples, and technical support as a cost share.

The DOE/PETC funding was secured as a result of a competitive award from the DOE/PETC Advanced NO_x Control program. The objective of this program is to develop advanced concepts for the removal of NO_x from flue gas emitted by coal-fired utility boilers or for the control of NO_x formation by advanced combustion modification techniques. Funded projects are required to focus on the development of technology that significantly advances the state of the art, using a process or a combination of processes capable of reducing NO_x emissions to 60 ppm or less. The concept must have successfully undergone sufficient laboratory-scale development to justify scaleup for further evaluation at the pilot scale (not to exceed 5 MW_e in size). Other requirements include production of a nonhazardous waste or a salable by-product. The concept should have application to both new and retrofit coal-fired systems and show the potential for a 50% cost savings when compared to a commercial selective catalytic reduction (SCR) process capable of meeting the 60-ppm NO_x emission limit.

The EERC approach to meeting the program objective involves the development of a CFF for simultaneous NO_x and particulate control. The idea of applying either a permanent or throwaway catalyst to a high-temperature fabric filter for NO_x control is not new (1-4). However, advances at OCF have shown that a high-activity catalyst can be applied to a high-temperature woven glass cloth, resulting in a fabric filter material that can operate at temperatures higher than commercially available, coated glass fabric. The NO_x is removed by catalytic reduction with ammonia to form nitrogen and water. The catalyst employed at this time is vanadium-titanium, but the exact catalyst composition and the unique method of applying the catalyst to high-temperature glass fabric are the property of OCF (5). Other catalyst options are being evaluated by OCF in order to improve catalyst performance and minimize catalyst cost.

Bench-scale experimental results have shown that over 90% NO_x removal can be achieved, that the catalyst-fabric has promising self-abrasion characteristics, and that the potential exists for substantially reduced cost compared to conventional SCR and fabric filtration technologies (6, 7). However, development of the technology required further evaluation of air-to-cloth ratio effects, ammonia slip, SO₂ oxidation to SO₃, temperature cycling, catalyst-coated fabric preparation, fuel impacts, fabric cleaning (reverse-gas versus pulse-jet), catalyst life (poisoning and resistance to erosion), and filter performance/life (particulate control, differential pressure, and durability).

2.0 SCOPE OF WORK

The specific approach used to address these issues is represented by the following:

- Task 1 – Program Definition**
- Task 2 – Design and Construct Test Unit**
- Task 3 – Experimental Program and Data Reduction**
- Task 4 – Conceptual Design and Economic Evaluation**
- Task 5 – Test Unit Removal**

Task 1, Program Definition, required preparation of a Project Management Plan. This document contains a detailed scope of work, project schedule, and project budget; identifies key project personnel; and presents an appropriate quality assurance/quality control (QA/QC) plan for the project. Task 2, Design and Construct Test Unit, was divided into three subtasks. Subtasks 2.1 and 2.2 involved the detailed design of the test facility on which the experimental program was performed, the construction of the test facility, and an operational shakedown of the system prior to initiating the experimental effort. Subtask 2.3 involved OCF preparation of the catalyst-coated fabric filters that were evaluated in the experimental effort.

Task 3, Experimental Program and Data Reduction, has four subtasks. Subtask 3.1, Fundamental Testing, is intended as a support effort to the primary experimental test plan. This effort should supply information needed to understand the process mechanism thoroughly, allow screening of additional fabric samples, address the issue of catalyst poisoning, and generally support the pilot-scale effort. Subtask 3.2, Process Testing/Reverse-Gas System, was intended to evaluate process performance in a pilot-scale reverse-gas fabric filter, identify and optimize important process variables, and provide data for a conceptual design. Subtask 3.3, Process Testing/Pulse-Jet System, evaluated process performance in a pilot-scale pulse-jet fabric filter. Subtask 3.4, Fabric Durability Testing/Pulse-Jet System, will evaluate catalyst-coated fabric durability/performance for up to 12,000 hours in a slipstream pulse-jet baghouse.

Based on the results of Task 3, a technical and economic assessment of the CFF concept, Task 4, Conceptual Design and Economic Evaluation, is nearing completion. Task 5, Test Unit Removal, requires the identification of all major test facilities, equipment, instruments, and hardware and their condition, ownership, and proposed disposition.

The EERC is the primary contractor for the project and is responsible for the management and direction of all technical and administrative project activities. The EERC has, specifically, performed all work associated with Task 1, Subtasks 2.1 and 2.2, and Task 3 and will perform Task 5.

OCF performed and/or supervised all work associated with Subtask 2.3, including manufacturing the "S"-glass fabric, coating the fabric, and manufacturing the filter bags for the reverse-gas and pulse-jet systems. This effort, as well as technical support, is being provided by OCF as a cost share to the project.

RE&C, as a subcontractor to the EERC, provided technical support for Task 1 and has nearly completed work on Task 4. EERC personnel involved in the Task 3 effort, and OCF personnel provided input to RE&C Task 4 activities.

The project schedule was based on a project start date of October 1, 1990, and originally assumed a project duration of 36 months. Therefore, the planned project completion date was September 30, 1993. As of the preparation of this document, a request has been made to extend the project completion date through March 31, 1994. The six-month extension will permit the continuation of Subtask 3.4 through November 1993 at no additional cost to the project sponsors. As of September 30, 1993, planned experimental activities for Subtasks 3.2 and 3.3 have been completed. Bench-scale experimental work for Subtask 3.1 is nearly complete, and some additional bench-scale work is planned in support of Subtask 3.4. Operation of the slipstream baghouse at the UND Steam Plant resumed in late July and is expected to continue through November 1993. Task 4 activities were ongoing during the past quarter and should be completed by late October 1993.

3.0 GOALS AND OBJECTIVES

The overall objective of this project is the development of a catalyst-coated fabric filter for simultaneous NO_x and particulate control. The catalyst-coated fabric filter must provide high removal efficiency for NO_x and particulate matter. An acceptable bag and catalyst life must be demonstrated, and process economics must show a significant cost savings when compared to a commercial SCR process and conventional particulate control. Specific goals include the following:

- Reduce NO_x emissions to 60 ppm or less
- Demonstrate particulate removal efficiency of > 99.5%
- Demonstrate a bag/catalyst life of > 1 year
- Control ammonia slip to < 25 ppm
- Show that CFF can achieve a 50% cost savings over conventional fabric filtration and SCR control technology
- Determine compatibility with SO₂ removal systems
- Show that the concept results in a nonhazardous waste product

Specific project activities to be completed during the past quarter (July through September 1993) were to include the following:

- Complete Subtask 3.1 – Fundamental Testing
- Continue Subtask 3.2 – Process Testing/Reverse-Gas System
- Continue Subtask 3.4 – Fabric Durability Testing/Pulse-Jet System
- Complete Task 4 – Conceptual Design and Economic Evaluation

4.0 ACCOMPLISHMENTS

4.1 Subtask 3.1 - Fundamental Testing

The planned bench-scale catalyst deactivation experiments were completed this past quarter. An experimental approach representing a worst-case scenario, where the catalyst-coated fabric filters are wetted as a result of an upset condition, was used. During such an upset condition, water may leach various components from the ash layer onto the fabric, creating an alkali-, acid-, or sulfur-rich solution. Depending on the nature of the upset condition, the wetted fabric would either quickly dry because of CFF operating temperatures or remain wetted for an extended period in the event of a forced system shutdown.

Fabric samples treated with an acid or base solution were tested after the solution was dried at 240°F on the fabric surface and then tested a second time after thorough washing with distilled water. Fabric samples treated with a slurry of the deactivation agent, resulting in a dried dust cake on the surface, were lightly washed with distilled water prior to testing in order to prevent simple fabric blinding from contributing to observed catalyst deactivation. Fabric samples treated with coal ash did not require washing. These bench-scale tests were designed to evaluate the effect of an upset condition on the reactivity of the catalyst-coated fabric with respect to NO_x reduction and ammonia slip.

Figure 1 illustrates the experimental system used to perform the bench-scale catalyst deactivation experiments. Primary system components include three parallel reactors housed in an electrically heated oven; multiple gas cylinders supplying the

Figure 1. Schematic of bench-scale reactor system.

necessary components (oxygen, ammonia, and nitric oxide in a nitrogen balance) for the simulated flue gas; and instrument calibration gases, mass flow controllers, flow indicators, and on-line analyzers for measurement of oxygen and nitric oxide concentrations. Ammonia concentrations were measured using calorimetric techniques.

The specific experimental approach involved treating individual catalyst-coated fabric samples with a potential deactivation agent, loading a fabric sample into each of the three reactors, and using a 3- to 4-hour heatup period with no gas flowing through the reactors. Once the reactors had reached the desired operating temperature, simulated flue gas flow was initiated, and desired gas constituent concentrations were verified. Each set of three experiments then required 2 to 3 hours in order to collect and verify the gas data. Specifically, multiple ammonia measurements were necessary during each experiment to ensure reliable data and to document good ammonia closure.

The catalyst-coated fabric type used for the catalyst deactivation experiments was 22-ounce woven S-glass fabric consisting of D-fibers (6.5-micron) prepared using seven coats of an organic-based vanadium/titanium catalyst. This is the same as the fabric type used during the pilot-scale pulse-jet tests. For the catalyst deactivation experiments, reactor temperatures were 650° to 660°F, and the filter face velocity was 4 ft/min. The simulated flue gas stream contained 700 to 725 ppm nitric oxide, sufficient ammonia to achieve an ammonia/NO_x molar ratio of roughly 0.8, roughly 3.5% oxygen, and a nitrogen balance.

Table 1 summarizes the results from the catalyst deactivations experiments completed. Each data set in the table represents a single experiment and ammonia closure was typically 97% to 103%. As presented in the table, the potential catalyst deactivation agents used included distilled water, tap water, hydrochloric acid (HCl), sulfuric acid (H₂SO₄), sodium hydroxide (NaOH), calcium oxide (CaO), calcium sulfate (CaSO₄), potassium sulfate (K₂SO₄), sodium sulfate (Na₂SO₄), sodium sulfite (Na₂SO₃), sodium chloride (NaCl), calcium chloride (CaCl₂), and three ash samples.

Baseline fabric performance was observed to be 71.5% NO_x reduction and 5.6% ammonia slip at an ammonia/NO_x molar ratio of 0.78. Results from the catalyst deactivation tests show that distilled water (70.4% NO_x reduction and 5.6% ammonia slip) had no effect on catalyst reactivity, and tap water (68% NO_x reduction and 6.9% ammonia slip) may have a minor effect. Both acids, 0.1M HCl and 0.1M H₂SO₄, appeared to totally destroy catalyst reactivity initially, but when the fabric samples were washed with distilled water and retested, catalyst reactivity was observed to be effectively recovered.

Deactivation experiments with 0.1M NaOH resulted in complete loss of catalyst reactivity, 2% NO_x reduction, and >80% ammonia slip. Washing this fabric sample did not produce any recovery of catalyst reactivity. Even when the NaOH concentration was decreased to 0.001M, NO_x reduction decreased to 58%. Ultimately, all of the sodium-based catalyst deactivation agents (NaOH, Na₂SO₄, Na₂SO₃, and NaCl) tested severely reduced the reactivity of the catalyst-coated fabric.

Of the three calcium-based catalyst deactivation agents (CaO, CaSO₄, and CaCl₂) tested, CaO and CaCl₂ resulted in the most significant decrease in catalyst reactivity, 11% to 15% NO_x reduction and 66.8% to 68.9% ammonia slip. The CaSO₄ did not decrease

TABLE 1

Bench-Scale Catalyst Deactivation Test Results ^{a,b}

Deactivation Agent	NH ₃ /NO _x Molar Ratio	% NO _x Removal	NH ₃ Slip, % of inlet NO _x
DE 992 Fabric, Baseline	0.78	71.5	5.6
Distilled H ₂ O	0.78	70.4	5.6
Tap H ₂ O	0.78	68.0	6.9
0.1M HCl	1.16	0.0	86.0
0.1M HCl, washed	0.85	73.4	2.76
0.001M HCl	0.81	71.4	
0.1M H ₂ SO ₄	0.85	1.0	80.7
0.1M H ₂ SO ₄ , washed	0.85	71.4	2.48
0.001M H ₂ SO ₄	0.81	58.4	---
0.1M NaOH	0.81	2.1	82.1
0.1M NaOH, washed	0.85	6.5	80.0
0.001M NaOH	0.81	58.4	---
CaO, washed	0.82	11.3	66.8
CaSO ₄ , washed	0.86	70.4	17.8
K ₂ SO ₄ , washed	0.86	74.1	9.2
Na ₂ SO ₄ , washed	0.86	26.5	57.0
Na ₂ SO ₃ , washed	0.82	2.4	74.1
NaCl, washed	0.81	8.7	70.2
CaCl ₂ , washed	0.81	14.9	68.9
Blacksville Bituminous Ash (low Ca, Na)	0.82	37.6	43.8
Falkirk Lignite Ash (high Ca, low Na)	0.82	34.7	44.6
Beulah Lignite Ash (high Ca, Na)	0.82	3.28	80.7

^a Typical reactor operating conditions for the catalyst deactivation experiments were a temperature of 650°–660°F, a face velocity of 4 ft/min, an inlet NO_x concentration of 700–725 ppm, and an NH₃/NO_x molar ratio of roughly 0.8.

^b Each data set in the table represents a single experiment. Closure on NH₃ was typically 97% to 103%.

NO_x reduction as significantly as the sodium-based materials or the other calcium-based materials tested, but there was a significant increase in the ammonia slip observed, with that value approaching 18% of the inlet NO_x concentration. Potassium sulfate also had an effect on catalyst reactivity, although substantially less significant than that of the other alkali species. In this case, ammonia slip increased to over 9% of the inlet NO_x concentration, as opposed to the 5% to 6% observed for the baseline fabric.

The three ash samples used in the series of experiments represent a bituminous coal and two lignites. Table 2 summarizes the chemical composition for each ash type. The bituminous coal ash contains very little alkali, one lignite ash contains a high level of calcium, and the other lignite ash contains high levels of both calcium and sodium. Results from these three experiments are consistent with those observed for the pure chemical deactivation agents tested. Catalyst reactivity was dramatically decreased for all three fabric samples, with the high-sodium ash demonstrating the greatest effect, 3.28% NO_x reduction and 80.7% ammonia slip. The two low-sodium ash samples decreased NO_x reduction to roughly 35% and increased ammonia slip to 44%.

Two general conclusions can be drawn from this data. First, condensation of an acid on the surface of the catalyst-coated fabric interferes with the reactivity of the catalyst. However, catalyst reactivity can be recovered by simply washing the acid from the surface of the catalyst/fabric. Second, exposing the catalyst-coated fabric to a basic or alkali solution will result in varying degrees of catalyst deactivation. A strong base, such as NaOH, will destroy catalyst reactivity. Alkaline solutions in general appear to have a severe negative affect on catalyst reactivity. Solutions containing sodium reduce catalyst reactivity more dramatically than calcium, and calcium more dramatically than potassium. The degree of catalyst deactivation also varies, depending on the exact chemical form of the sodium or calcium.

TABLE 2
Coal Ash Analysis for Catalyst Deactivation Tests

	Blacksville Bituminous Coal	Beulah Lignite	Falkirk Lignite
Oxides, wt% of ash			
SiO ₂	46.87	25.5	42.2
Al ₂ O ₃	22.58	12.3	12.1
Fe ₂ O ₃	18.92	11.2	12.6
TiO ₂	0.88	1.1	0.9
P ₂ O ₅	0.32	0.5	0.0
CaO	5.40	18.1	20.8
MgO	1.01	4.3	7.0
Na ₂ O	0.77	13.07	0.6
K ₂ O	1.44	0.6	1.5
SO ₃	1.81	12.9	1.8

Based on the results observed, a number of additional experiments could be performed. For example, chlorine or chloride could be tested at two or three concentrations to determine the effect on catalyst reactivity and delineate the effects observed for tap water, NaCl, and CaCl₂. Also, three fabric samples could be removed from one catalyst-coated bag used during the last 500-hour pulse-jet test. One of the three samples would be a baseline, a second would be treated with H₂SO₄, and the third with distilled water. The purpose of these experiments would be to determine the effect of an acid dew point versus a moisture dew point on catalyst reactivity with some residual ash on the fabric. A second set of three experiments could be completed with fabric samples collected from a bag removed from the slipstream baghouse at the UND Steam Plant. In this case, the residual dust would represent a subbituminous ash having a higher alkali content. A further review of the data will be made before specific recommendations are made concerning additional bench-scale experiments.

4.2 Subtask 3.2 - Process Testing/Reverse-Gas System

Subtask 3.2 activities this past quarter included completion of routine reporting requirements, presentation of a paper, a visit to the OCF Science and Technology Center, performance of some limited bench-scale fabric testing, and further evaluation of the 500-hour test data. A paper, entitled "Catalytic Fabric Filtration (CFF) for Simultaneous NO_x and Particulate Control," was presented at the Ninth Annual Coal Preparation, Utilization, and Environmental Control Contractors' Conference, held July 19-22, 1993, in Pittsburgh, PA. Copies of the paper were included as an attachment to the April Project Status Report.

A visit to the OCF Science and Technology Center took place on September 29, 1993. The purpose of the meeting was to discuss pilot-scale test results, the results of the economic evaluation, and future catalyst-coated fabric filter development activities. Meeting participants included the EERC Project Manager, Cam Martin of RE&C, and several OCF personnel.

As a result of the meeting held September 29, 1993, RE&C will be making a few minor changes to the economic evaluation, and the EERC will prepare two proposals for consideration by OCF. The first change to be made to the economic evaluation will be to present equipment costs on an installed rather than uninstalled basis. Also, a second set of leveled costs will be presented that do not contain all the contingencies in order to demonstrate the potential cost advantages of the catalytic fabric filter concept, assuming an equivalent level of technical development.

The EERC will prepare two proposals for consideration by OCF. One proposal will address the continued operation of the slipstream baghouse at the UND Steam Plant. The purpose of the proposal will be to secure funding to permit operation of the system for up to 16,000 hours, demonstrating roughly two years of operation on a single set of bags. A second proposal will address bench-scale fabric screening tests in support of OCF development efforts to improve upon the performance of the catalyst-coated fabric observed to date.

In the Quarterly Technical Progress Report for the period April through June 1993, the EERC reported results from some initial bench-scale experiments using fabric samples from filter bags used during the 100- and 500-hour pilot-scale tests, as well as two bags

used during the performance/durability test at the UND Steam Plant. The intent was to evaluate these fabric samples in the bench-scale system in order to determine if there were any differences in catalyst-coated fabric reactivity, as well as the effect of exposure to flue gas as a function of time. The experimental approach, which was described in a previous report, will not be repeated here (8).

Results of the bench-scale fabric tests completed, including some data not previously reported, are summarized in Figure 2. Each set of data points (NO_x reduction and ammonia slip) represents an arithmetic average of three individual experiments, one experiment for each of the three fabric samples (top, middle, and bottom) removed from each bag tested. The results are presented in this manner because variation in the data for a single bag was typically less than 2% NO_x reduction and closure on the ammonia was typically 97% to 103%.

The four observations made in the previous report with respect to this bench-scale data are still valid. First, the fabric samples tested from the two bags removed from the slipstream baghouse at the UND Steam Plant are demonstrating NO_x reduction and ammonia slip levels similar to those observed during the 500-hour test. These data imply that there has not been any significant decrease in catalyst reactivity as a function of the number of hours of flue gas exposure for up to 1642 hours.

Figure 2. NO_x removal and ammonia slip versus ammonia-to- NO_x molar ratio for bench-scale fabric screening tests.

Second, all of the fabric samples that had been exposed to a flue gas stream in the pilot-scale pulse-jet baghouse during the 100-hour and 500-hour parametric tests are showing equivalent performance in the bench-scale system. Therefore, all of the catalyst-coated bags used during the pilot-scale pulse-jet tests completed appear to have comparable catalyst reactivity after 100 hours of flue gas exposure.

Third, an additional set of bench-scale experiments was completed with fabric samples from bags used during pilot-scale test PTC-BT-430. Initial results indicated that these fabric samples may be slightly more reactive than the other fabric samples tested. Subsequent bench-scale tests have shown fabric samples collected from bags used during test PTC-BT-430 demonstrate reactivity comparable to the other fabric samples tested and the initial data set is within the observed data variability.

Finally, the ammonia slip levels observed in the bench-scale data are similar to those observed in the data set from the 100- and 500-hour pilot-scale experimental periods. The exception is one bench-scale baseline data set represented by a new heat-treated fabric sample. In this case, the ammonia slip was significantly lower in the bench-scale test, 2% versus 7% of the inlet NO_x concentration. A possible explanation for the difference is that the NH_3 closure was only 91% for this particular baseline bench-scale test, indicating that the actual NH_3 slip value was probably higher than the value measured.

Figure 3 summarizes all of the coal- and oil-fired pilot-scale pulse-jet data generated. The data show that, based on results from the 500-hour tests, 80% NO_x reduction can be achieved at an air-to-cloth ratio of 3 to 3.5 ft/min, an NH_3/NO_x molar ratio of 0.85, and roughly 7% NH_3 slip, based on the inlet NO_x concentration. Data from the 100-hour pulse-jet tests generally indicate better performance (higher NO_x reduction and lower

Figure 3. NO_x removal and ammonia slip versus ammonia-to- NO_x molar ratio for coal- and oil-fired test periods.

NH₃ slip). However, data from the first 100 hours of each 500-hour test also indicated better performance, indicating that fabric reactivity decreased slightly during the first 100 hours of flue gas exposure. Other variability in the data is due to the various fuels fired (Blacksville bituminous coal, Black Thunder subbituminous coal, and fuel oil) and the range of air-to-cloth ratios represented (3 to 6 ft/min).

The planned pilot-scale experimental activities outlined in the original scope of work have been completed. Remaining activities will include routine reporting and preparation of papers or journal articles deemed appropriate. No additional bench-scale experimental work or fabric analytical characterization is anticipated at this time, with the exception of support activities with respect to operation of the slipstream baghouse at the UND Steam Plant.

4.3 Subtask 3.3 - Process Testing/Pulse-Jet System

The three 100-hour pulse-jet tests planned for this subtask were completed in July 1992, and the 500-hour test was completed in August 1992. Results were presented at a project review meeting in October 1992 and were summarized in the Quarterly Technical Progress Report for the period July through September 1992. Subtask 3.3 activities have been completed, with the exception of final reporting activities and the preparation of any papers or journal articles deemed appropriate.

4.4 Subtask 3.4 - Fabric Durability Testing/Pulse-Jet System

The slipstream baghouse resumed operation on July 29, 1993, and operated for 1521 hours from July 29 through September 30, 1993, resulting in 3986 cleaning cycles. As of September 30, 1993, the baghouse had accumulated 3961 hours of operating time. During the past quarter, the baghouse operated at an average flue gas temperature of 500° to 600°F, an air-to-cloth ratio of 4 to 5 ft/min, and a baghouse differential pressure of nominally 2 to 4 in. W.C.

Figure 4 presents baghouse mean temperature as a function of time for the entire 3961 hours of operation completed through September 30, 1993. Baghouse temperature is presented as an arithmetic mean value based on four thermocouples in the baghouse. The variability in baghouse mean temperature is the result of swings in boiler load. In general, the baghouse mean temperature has been relatively low, ranging from 500° to 600°F, because of relatively low steam demand in the fall of 1992, the spring of 1993, and the early fall of 1993 and the high excess air levels at which the boiler is operating. If the boiler had operated during the winter months (December, January, and February) and/or at more typical excess air levels, average baghouse temperature would have been in the 600° to 700°F range. Because of persisting low baghouse mean temperatures, the EERC Project Manager has raised the baghouse face velocity from 4 to 4.5 ft/min to increase average baghouse temperature. Face velocity will probably be increased further in October if low steam load demand is anticipated.

Figure 5 presents baghouse face velocity as a function of time for the entire 3961 hours of operation. In order to determine face velocity, flue gas flow rates are monitored on a continuous basis using an annubar flow element and verified twice daily by taking pilot measurements. Initially, baghouse face velocity was roughly 3.5 ft/min. After about 500 hours of operation, the face velocity was increased to 4 ft/min in an attempt to

maintain baghouse mean temperature as average boiler load decreased. In November 1992, the face velocity was decreased to 3 ft/min in order to prevent the baghouse mean temperature from exceeding 700°F. In April 1993, the face velocity was again increased to 4 ft/min in order to maintain the baghouse mean temperature above 500°F. During the past quarter, face velocity was increased from roughly 4 ft/min to slightly over 4.5 ft/min in order to increase baghouse mean temperature.

Figure 4. Steam plant baghouse mean temperature versus run time.

Figure 5. Steam plant baghouse face velocity versus run time.

During the July, August, September operating period, the baghouse was cleaned as a function of differential pressure. The cleaning cycle trigger point was 6 in. W.C. in July and August, resulting in 2940 cleaning cycles. In late August, the cleaning cycle trigger point was reduced from 6 to 4 in. W.C. in order to maintain a 20- to 30-minute cleaning frequency. Baghouse operation in September resulted in 1046 cleaning cycles.

Figure 6 presents baghouse differential pressure as a function of time for the entire 3961 hours of operation. For most of the 3961 hours of operation completed, the baghouse differential pressure has been effectively controlled between 2 and 4 in. W.C. using on-line cleaning. In May 1993, ash loading to the baghouse was increased from < 2 gr/scf to > 2 gr/scf. This change resulted in a significant increase in the cleaning cycle frequency, and the bags were not cleaning efficiently. In order to prevent frequent cleaning, a < 20 -minute cleaning cycle frequency, and improve bag cleaning, it was necessary to increase the cleaning cycle trigger point from 4 to 6 in. W.C. During the past quarter, the cleaning cycle trigger point was again reduced to 4 in. W.C. in order to maintain a 20- to 30-minute cleaning frequency. A change in ash properties, probably an increase in particle-size distribution, is believed to be responsible for the change in cleaning frequency. Total cleaning cycles as of September 30, 1993, number 10,738. The pulse-air reservoir pressure was 43 psig and the pulse duration was 0.1 seconds during the July, August, September operating period.

Figure 6. Steam plant baghouse differential pressure versus run time.

Ash injection to augment the particulate mass loading from the stoker-fired boiler was continuous during the July, August, September operating period. The injection ash used during this period was a subbituminous ash collected from a pulse-jet baghouse operating on one of the stoker-fired boilers.

Table 3 present x-ray fluorescence (XRF) analysis results for baghouse hopper ash samples collected in August and September. Primary components included silica, alumina, calcium, and magnesium, all reported as oxides. The loss-on-ignition (LOI) for these samples was 8.91% and 7.42%, respectively, resulting from carbon carryover from the stoker-fired boiler.

Particulate sampling was performed on August 4 and September 10 and 29, 1993. Tables 4 and 5 summarize EPA Method 5 and multicyclone sampling data, respectively, for the entire 3961 hours of operation completed. Results showed particulate collection efficiency ranged from 99.98% to 99.99% for six 2-hour sampling periods for an average inlet mass loading of 2.0 to 2.3 gr/scf. Measured outlet emissions ranged from 0.0002 to 0.0005 gr/scf.

Figures 7, 8, and 9 present baghouse emissions data generated using the APS sampling system. Total and respirable mass emissions were low, $< 0.1 \text{ mg/m}^3$, except during cleaning cycles that resulted in emission spikes in the 1- to 5-mg/m^3 range. Emissions based on integrated averages ranged from 0.02 to 0.1 mg/m^3 .

Multicyclone sampling indicated that roughly 80% of the fly ash entering the baghouse had an aerodynamic diameter of > 8 microns. Figure 10 summarizes all of the multicyclone data resulting from operation of the pulse-jet baghouse at the UND Steam Plant. The data show that during specific sampling periods, 74% to 97% of the fly ash entering the baghouse had an aerodynamic diameter of > 10 microns.

TABLE 3

XRF Analysis of Steam Plant Baghouse Hopper Ash, August and September 1993

Oxide	August, wt%	September, wt%
SiO ₂	39.44	42.11
Al ₂ O ₃	20.86	22.11
Fe ₂ O ₃	2.20	1.82
TiO ₂	1.12	1.21
P ₂ O ₅	0.5	0.37
CaO	21.59	19.09
MgO	8.56	8.37
Na ₂ O	0.49	0.42
K ₂ O	0.34	0.33
SO ₃	4.83	4.17
Loss-on-Ignition	8.91	7.42

TABLE 4
Steam Plant Particulate Sampling Data

Test Date	Inlet, gr/scf	Outlet, gr/scf	% H ₂ O	% Efficiency
07-16-92	1.5542	---	8.1	---
07-16-92	---	0.0001	6.4	99.992
07-16-92	2.5491 ^a	---	7.1	---
08-20-92	1.7417	---	6.3	---
08-20-92	17.6786	---	7.3	---
08-20-92	---	2.5643	6.6	85.495
08-20-92	14.9548 ^a	---	6.1	---
10-29-92	4.0363	---	4.6	---
10-29-92	---	0.0008	5.2	99.986
10-29-92	---	0.0010	4.2	99.974
10-29-92	5.7311 ^a	---	3.7	---
11-19-92	3.1900	---	6.7	---
11-19-92	---	0.0007	6.0	99.979
11-19-92	---	0.0011	5.5	99.965
11-19-92	2.6910 ^a	---	4.8	---
04-27-93	1.6709 ^a	---	5.0	---
04-27-93	---	0.0001	5.4	99.994
04-27-93	---	0.0002	5.3	99.988
05-14-93	2.2604 ^a	---	6.2	---
05-14-93	---	0.0003	5.1	99.987
05-14-93	---	0.0003	5.1	99.987
08-04-93	2.2821 ^a	---	5.4	---
08-04-93	---	0.0003	4.5	99.987
08-04-93	---	0.0004	4.2	99.983
09-10-93	1.7974 ^a	---	3.4	---
09-10-93	1.9520	---	3.9	---
09-10-93	---	0.0002	5.2	99.988
09-10-93	---	0.0002	4.5	99.988
09-29-93	2.2451 ^a	---	4.5	---
09-29-93	2.2124	---	7.4	---
09-29-93	---	0.0004	5.8	99.981
09-29-93	---	0.0005	5.5	99.979

^a Multicyclone sampling.

TABLE 5
Steam Plant Multicyclone Data

07-16-92	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	9.24	6.07	3.27	2.23	0.93	---
Mass Collected, g	3.4958	0.3263	0.2812	0.1947	0.1327	0.0394
% Total Mass	78.21	7.30	6.29	4.35	2.97	0.88
Mass Less Than D ₅₀ , cumulative %	21.79	14.49	8.20	3.85	0.88	---
Total Mass Collected = 4.4700 g, Dust Loading = 2.5491 gr/scf, % Isokinetic = 99.0						
08-20-92	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	8.67	5.49	2.93	2.01	0.84	---
Mass Collected, g	27.9474	0.4742	0.1699	0.0940	0.0730	0.0261
% Total Mass	97.09	1.65	0.59	0.33	0.25	0.09
Mass Less Than D ₅₀ , cumulative %	2.91	1.26	0.67	0.34	0.09	---
Total Mass Collected = 28.7845 g, Dust Loading = 14.9548 gr/scf, % Isokinetic = 100.9						
10-29-92	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	10.27	7.09	3.88	2.61	1.08	---
Mass Collected, g	8.6404	0.0919	0.0397	0.0250	0.0278	0.0175
% Total Mass	97.72	1.04	0.45	0.28	0.31	0.20
Mass Less Than D ₅₀ , cumulative %	2.28	1.24	0.80	0.51	0.20	---
Total Mass Collected = 8.8424 g, Dust Loading = 5.7311 gr/scf, % Isokinetic = 90.6						

continued . . .

TABLE 5 (continued)
Steam Plant Multicyclone Data

11-19-92	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	8.35	5.14	2.72	1.89	0.79	---
Mass Collected, g	5.2629	0.1398	0.0464	0.0182	0.0071	0.0156
% Total Mass	95.86	2.55	0.85	0.33	0.13	0.28
Mass Less Than D ₅₀ , cumulative %	4.14	1.59	0.75	0.41	0.28	---
Total Mass Collected = 5.4901 g, Dust Loading = 2.691 gr/scf, % Isokinetic = 100.0						
04-27-93	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	8.50	5.17	2.73	1.91	0.80	---
Mass Collected, g	2.5941	0.2837	0.2670	0.1340	0.0817	0.0262
% Total Mass	76.60	8.38	7.88	3.96	2.41	0.77
Mass Less Than D ₅₀ , cumulative %	23.40	15.03	7.14	3.19	0.77	---
Total Mass Collected = 3.3867 g, Dust Loading = 1.6709 gr/scf, % Isokinetic = 102.9						
05-14-93	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	7.38	4.21	2.20	1.55	0.64	---
Mass Collected, g	4.4662	0.7465	0.1675	0.0423	0.0236	0.0225
% Total Mass	81.67	13.65	3.06	0.77	0.43	0.41
Mass Less Than D ₅₀ , cumulative %	18.33	4.68	1.62	0.84	0.41	---
Total Mass Collected = 5.4685 g, Dust Loading = 2.260 gr/scf, % Isokinetic = 103.3						

continued . . .

TABLE 5 (continued)
Steam Plant Multicyclone Data

08-04-93	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	6.77	3.85	2.00	1.40	0.56	---
Mass Collected, g	4.0157	1.7763	0.2531	0.1626	0.0536	0.0131
% Total Mass	64.00	28.31	4.03	2.59	0.85	0.21
Mass Less Than D ₅₀ , cumulative %	36.00	7.69	3.65	1.06	0.21	---
Total Mass Collected = 6.2744 g, Dust Loading = 2.2821 gr/scf, % Isokinetic = 103.2						
09-10-93	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	9.51	6.32	3.42	2.32	0.96	---
Mass Collected, g	2.6665	0.1977	0.0847	0.0426	0.0503	0.0182
% Total Mass	87.14	6.46	2.77	1.39	1.64	0.60
Mass Less Than D ₅₀ , cumulative %	12.86	6.40	3.63	2.24	0.60	---
Total Mass Collected = 3.0600 g, Dust Loading = 1.7974 gr/scf, % Isokinetic = 100.6						
09-29-93	CY1	CY2	CY3	CY4	CY5	Backup Filter
D ₅₀ , μm	9.22	6.05	3.26	2.22	0.92	---
Mass Collected, g	3.5055	0.2566	0.1211	0.575	0.0583	0.0222
% Total Mass	87.18	6.38	3.01	1.43	1.45	0.55
Mass Less Than D ₅₀ , cumulative %	12.82	6.44	3.43	2.00	0.55	---
Total Mass Collected = 4.0212 g, Dust Loading = 2.2451 gr/scf, % Isokinetic = 104.4

Figure 7. Mass emissions and pressure drop as a function of time for the steam plant baghouse, August 4, 1993.

Figure 8. Mass emissions and pressure drop as a function of time for the steam plant baghouse, September 10, 1993.

Figure 9. Mass emissions and pressure drop as a function of time for the steam plant baghouse, September 29, 1993.

Figure 10. A summary of multicyclone data for ash collected in the steam plant baghouse.

Sampling was not completed at the outlet of the baghouse to determine sulfur trioxide (SO_3) concentration. All previous sampling results have shown SO_3 concentrations downstream of the baghouse to be less than 1 ppm. Therefore, further SO_3 sampling is not warranted.

The boiler from which the slipstream baghouse draws flue gas is expected to operate on a continuous basis for the remainder of the 93/94 heating season with one exception: The boiler is expected to be shut down temporarily at some point during the heating season in order to accommodate the installation of a variable-speed drive on the induced-draft (ID) fan. However, the schedule for the shutdown has not been set. Sufficient funding is available to operate the slipstream baghouse in October and November 1993. It does not appear that it will be possible to operate the slipstream baghouse beyond November without additional funding.

Assuming the slipstream baghouse operates continuously during the months of October and November 1993, total accumulated operating hours will be roughly 5400. As stated earlier in this report, the EERC will be submitting a proposal to OCF for their consideration concerning the continued operation of the slipstream baghouse. The purpose of the proposal will be to secure funding to permit operation of the system for up to 16,000 hours, demonstrating roughly two years of operation on a single set of bags. Specifically, the proposal will request that OCF provide 60% of the required funding, with the remaining 40% to be requested from the U.S. DOE as a joint venture activity outside the scope of this contract.

4.5 Task 4 – Conceptual Design and Economic Evaluation

Raytheon Engineers & Constructors (RE&C) has essentially completed work on the conceptual design and economic evaluation. Preliminary results from the new 500-MW plant case study were presented by RE&C at the April 29, 1993, project review meeting held at the EERC. Work on the retrofit case study was completed, and a draft of the Task 4 report was made available to EERC and DOE/PETC personnel for review in mid-July. Copies of the draft report, along with EERC review comments, were forwarded to OCF, Con Edison, and ESEERCO personnel in mid-August. As of the preparation of this report, review comments have been received from all of the project participants.

As previously stated, RE&C will be making a few minor changes to the economic evaluation as a result of the meeting held with OCF personnel in late September. First, equipment costs will be presented on an installed rather than uninstalled basis. Also, a second set of levelized costs will be presented that do not contain all the contingencies in order to demonstrate the potential cost advantages of the CFF concept, assuming an equivalent level of technical development. Copies of the final Task 4 report are expected to be distributed to project participants by early November.

5.0 KEY PERSONNEL STAFFING REPORT

Table 6 presents planned versus actual work hours for key EERC personnel involved in the CFF project through September 1993. Work hours reported for Mr. Robie of RE&C represent hours invoiced through August 1993.

TABLE 6

**Planned Versus Actual Work Hours
for Key Project Personnel Through September 1993**

Key Personnel	Planned Hours	Actual Hours	Percentage of Total Available Work Hours Used
Greg F. Weber	2290	2025	88
Dennis L. Laudal	3880	1099	28
Chris Robie	364	38	10

6.0 REFERENCES

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