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**Coal-Fueled Diesel Technology Development
Emissions Control**

Topical Report

**W. Van Kleunen
S. Kaldor
E. Gal
M. Mengel
M. Arnold**

January 1994

Work Performed Under Contract No.: DE-AC21-88MC23174

**For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia**

**By
General Electric Environmental Services, Inc.
Lebanon, Pennsylvania**

MASTER

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**DOE/GETS TOPICAL REPORT
SUMMARY**

SUMMARY

GEESI Emissions Control program activity ranged from control concept testing of 10 CFM slipstream from a CWS fuel single cylinder research diesel engine to the design, installation, and operation of a full-size Emissions Control system for a full-size CWS fuel diesel engine designed for locomotive operation. Although the full-size system was installed and operated at the engine test laboratory, the system design was commensurate with the size and space constraints necessitated by locomotive operation.

Early 10 CFM slipstream testing program activity was performed to determine Emissions Characteristics and to evaluate Emissions Control concepts such as Barrier filtration, Granular bed filtration, and Cyclone particulate collection for reduction of particulate and gaseous emissions. Program objectives emerged to control particulate SO_2 and NO_x emissions equal to or less than conventional fuel diesel engine emissions. Slipstream testing indicated each control concept to be viable, although the cyclone alone was not judged to be a satisfactory absolute system, but applicable as a first stage system or installed as a particulate collector to protect the diesel engine turbocharger.

Use of sorbent injection into the engine exhaust gas upstream of the barrier filter or use of sorbent media in the granular bed filter were found to provide reduction of exhaust gas SO_2 and NO_x , in addition to collection of ash particulate.

Emergence of the use of barrier filtration as a most practical Emissions Control concept disclosed a need to improve cleanability of the filter media in order to avoid reduction of turbocharger performance by excessive barrier filter pressure drop. Continuous precoating of the filter media using a sorbent particulate was found to be an effective procedure to avoid this situation.

The next progression of program activity, after the slipstream feasibility stage, was 500 CFM cold flow testing of control system concepts. Cyclone alone systems were tested in the laboratory simulating the particulate service determined from the CWS fuel slipstream emissions characterization.

A barrier filter was designed to utilize flat sheets of porous metal fiber filter media, instead of conventional cylindrical "candles". This design of filter media was found to represent the most advantageous use of size and space constraints imposed by a railroad locomotive installation. Cold flow testing of this "Envelope Filter" was performed using particulate representing CWS fuel ash, as well as particulate representing continuous injection of Sorbent/Precoat. Although the Envelope Filter was found to be a

DOE/GETS TOPICAL REPORT SUMMARY

satisfactory design concept, cleanability of the filter media was found to be dependent upon use of appropriate filter media composition and sufficient use of continuous injection of Sorbent/Precoat particulate.

A granular bed filter was also designed and constructed for 500 CFM cold flow operation, but was not tested because the Envelope Filter had emerged as the preferred Emissions Control concept.

Interest in improving filter media cleanability led to investigations of Electrostatic Enhanced operation using high voltage to impart an electrical charge to the particulate entering the Envelope Filter. Successful application of this principle could lead to increased porosity of the particulate deposition on the filter media and permit a reduction of operating pressure drop while maintaining optimum contact of the sorbent with the gas stream. However, it was not possible to demonstrate performance merit for this design embellishment which was commensurate with the complications for installation.

The successful completion of 500 CFM cold flow testing of the Envelope Filter led to a subsequent progression to a similar configuration Envelope Filter designed to operate at 500 CFM hot gas flow from the CWS fuel research diesel engine in the GETS engine test laboratory. This Envelope Filter included the design aspect proven by cold flow testing as well as optimization of the selection of the installed filter media.

Hot gas testing of the installed Envelope Filter revealed deficient particulate collection which was suspected to be caused by an unsatisfactory design for the attachment of the filter media. A similar problem had also occurred during the cold flow testing. Satisfactory pressure drop operation was achieved when operating with continuous injection of inert precoat particulate, as well as with Sodium Bicarbonate sorbent particulate. Development of a vendor source for Copper Oxide coated Alumina powder Sorbent/Precoat particulate had not yet been performed and prevented a demonstration of the suitability of this process.

Vendor sources for Copper Oxide:Alumina Sorbent/Precoat were, subsequently, developed for procurement of quantities necessary for the eventual operation of the full size Envelope Filter. Studies were performed for the regeneration of the sorbent from Copper Sulfate reacted sorbent back to the active Copper Oxide state and for the removal of contaminating CWS ash. Because of lack of a timely supply of the Sorbent/Precoat material, a pilot sorbent regeneration system was designed and constructed, but was not operated, to demonstrate the process. Sorbent procurement was also performed for throwaway type Sodium Bicarbonate sorbent.

DOE/GETS TOPICAL REPORT SUMMARY

The extrapolation of the 500 CFM hot gas Envelope Filter design to the full size 20,000 CFM system was planned to be preceded by a Component Development stage consisting of cold flow testing of several full-size filter envelopes. Because of insufficient project schedule time to delay the design of the full size Envelope Filter, a test facility was designed, but was not constructed and tested.

A full-size Envelope Filter was designed and installed to operate connected to the 20,000 CFM full size CWS fuel diesel engine, which was installed in the engine test laboratory. The Envelope Filter was designed in accordance with all optimized design aspects developed by previous cold flow and hot gas design optimizations. An additional design embellishment, which was not previously investigated, was the installation of vertical baffles between adjacent filter envelopes to improve the cleanability of the larger size envelopes. The configuration of the Envelope Filter was designed to also be installed on a railroad locomotive, but this program task had previously been deleted from the program scope.

Operation of the full-size Envelope Filter was delayed because of unreliable operation of the full-size CWS fuel diesel engine. Eventually, to permit some operation of the Emissions Control system, the engine was operated at reduced load using conventional diesel fuel without CWS fuel. However, sulfur was added to the diesel fuel to permit evaluation of the SO_2 and NO_x reduction processes.

One successful test was performed using Copper Oxide sorbent. Test results were satisfactory in regard to particulate collection and filter pressure drop. However, SO_2 and NO_x reduction performance was less than expected because of reduced exhaust gas temperature resulting from the reduced load operation. Another test was attempted using Sodium Bicarbonate sorbent, but could not be completed because of plugging of the sorbent feed system.

**DOE/GETS TOPICAL REPORT
INTRODUCTION**

INTRODUCTION

This project, performed by General Electric Environmental Services, Inc. (GEESI), was performed as a subcontract to GE Transportation Systems (GETS), who was the prime contractor to the US Department of Energy, Morgantown Energy Technology Center, in accordance with DOE Contract DE-AC21-88MC23174 for Clean Coal Technology, Coal Fuel Diesel Engines. GEESI's function in regard to this project was for the determination of a system design for control of particulate and gaseous emissions from the coal-water-slurry (CWS) fuel engine, which was suitable for installation on a railroad locomotive. The design of the diesel engine for CWS fuel operation was performed entirely by GETS. Other program research was performed by GE Corporate Research and Development (GECRD) to determine sorbent processes for the reduction of CWS fuel diesel engine exhaust SO_2 and NO_x . These processes were subsequently incorporated into the design and operation of the Emissions Control System developed by GEESI.

This report discusses Emissions Control program activity performed from January 1990 through the completion of program diagnostics in September of 1993. An earlier program topical report issued in March 1990 discussed previous activity from the beginning of the program in September 1988 through December 1989.

The structure of planned program tasks is described by "Revised Work Statement Definition for Completion of Program Basis-of-Estimate" and "Program Schedule for Basis-of-Estimate to Complete Program", as enclosed in Appendix I. This Basis-of-Estimate was developed as part of a Cost-to-Complete estimate which was performed in October 1990. At that time, the program had progressed to a point which permitted significantly improved visibility of program strategy to complete the program objectives. The organization of this Topical Report will follow the program structure as described by the revised Work Statement.

A large content of this report consists of the design drawings of equipment which were designed as well as designed and constructed for various program task experiments. This documentation is enclosed in identified Appendix locations. Technical discussion of various program task activity, consisting of Tables and Figures, are also enclosed in identified Appendix locations apart from the technical discussion.

The report is organized in separate chapters in accordance with Work Statement major tasks. Some of the program tasks were not performed at all, or not performed completely, in accordance with subsequent changes of the planned program content, or by necessity to permit completion of the most important program tasks by the end of the program schedule.

A P P E N D I X I

**COAL FUEL DIESEL TECHNOLOGY DEVELOPMENT
DOE/GETS CONTRACT S9513**

**REVISED WORK STATEMENT DEFINITION (REVISED 10/30/90)
FOR COMPLETION OF PROGRAM
BASIS OF ESTIMATE**

TASK 1: Conceptual Commercial System Design and Research Definition

STATUS: Complete

TASK 2: Emissions Applied R&D

STATUS: In progress

SUBTASK 2.1: Emissions Applied R&D Test Plan

STATUS: Complete

SUBTASK 2.2: Test Implementation and Data Analysis

STATUS: In progress

SUB-SUBTASK 2.2.1: Program Scope - Pilot scale cold flow testing of emission control concepts in GEESI Laboratory: Design, procure and install test facilities for cyclone alone, envelope type barrier filter (EF), and granular bed filter (GBF) alone. Installation phase will be performed by GEESI personnel and will include site preparation (fan and ductwork system, instrumentation, test equipment, effluent final filter, etc.) and test supplies (silica powder to simulate CWM fuel diesel engine exhaust particulate, alumina powder to simulate sorbent/precoat used with barrier filter).

STATUS: Cyclone alone: design, procure/fabricate, and install complete; EF: design, procure and install complete; GBF alone: design in progress - assume complete at 10/1/90, procure & install have not been started.

SUB-SUBTASK 2.2.2: Program Scope - Pilot scale cold flow testing of emission control concepts in GEESI Laboratory: Testing of test facilities for cyclone alone, EF, and GBF alone.

STATUS: Cyclone alone: testing complete; EF: testing in progress - assume complete at 11/1/90; GBF alone: testing not started.

SUB-SUBTASK 2.2.3: Program Scope - Pilot scale testing of emission control concepts in GETS single cylinder CWM fuel diesel engine test cell: Design, procure, and install test facilities for EF, and GBF and cyclone. Program task will also include test cell modification which will be applicable to all control concept equipment (ductwork, flow control valve, isolation valves, instrumentation and controls, sorbent/precoat system for EF operation only, heated air system preheat equipment - see GEESI Dwg. S9513/GA-800, -801, -802, -803 & -805. System operating conditions will be 500-800 ACFM engine exhaust at 700 F. Operating pressure upstream of flow control valve + 25 psig. Operating pressure downstream of flow control valve + 40 in. W.G. (+ 1.4 psig).

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SUB-SUBTASK 2.2.3: CONTINUED

Design of collector concept equipment is expected to be similar to cold flow testing facilities.

For cyclone see GEESI Dwg. No. S9513/MD-800 & -801. For EF, see GEESI Dwg. No. S9513/FA-800, -801, -802, -803, -804, -805, -806, -807 & -810.

For GBF see GEESI Dwg. No. S9513/FA-860, -861, -862, -863, -864, -865, -866 & -870.

Installation of cell modification equipment will be performed by an outside contractor. GEESI will be responsible for providing construction planning for contractor procurement.

Installation construction will be monitored by GETS and GEESI Project Team and/or construction supervision personnel. Design of collector concept equipment and construction planning shall be commensurate with reconfiguration of facility for collector configuration iterations by GEESI project team and GETS personnel, without need for outside contractor.

SUB-SUBTASK 2.2.4: Following installation of cell modification and initial collector concept equipment, GEESI project team personnel will complete installation of I&C equipment and prepare same for test data acquisition logistics. All system controls - gas flow, isolation valves, high temperature interlocks, etc. will be calibrated and verified for proper and safe test operation.

SUB-SUBTASK 2.2.5: Two collector concept systems will be tested, as described by 2.2.3, in accordance with 2.2.1 plan. All testing activity, including changes of collector concept equipment, will be performed by GEESI project team personnel, assisted by GETS personnel.

SUB-SUBTASK 2.2.6: Following completion of 2.2.5 testing, test results will be evaluated to select a satisfactory candidate control concept to be carried forward into subsequent program task activity.

SUBTASK 2.3: Applied R&D Test Program Topical Report: A report will be prepared and submitted detailing the performance results of Task 2. Report activity will be performed by GEESI program team personnel.

TASK 3: Component Development Program: The purpose of this program task will be to develop the design of full size collector system components for the candidate concept selected in 2.2.6, which for the purpose of this plan is assumed to be the envelope filter collector concept. In consideration that all previous collector concept testing was performed using smaller than full size components, this activity is a necessary activity. Testing will be performed in GEESI Laboratory by GEESI project team personnel, in a cold flow testing mode.

SUBTASK 3.1: Component Development Test Plan: A test plan will be developed for assumed EF collector concept equipment, depending upon a successful conclusion of 2.2.6. An initial function of this plan will be consideration of the interaction of gas flow capacity with performance criteria, such as pressure drop and particulate collection. Variable component materials and media will also be factored into this matrix. A test plan will be developed to determine the most favorable combination of factors for projection to design of a full scale collector system.

Two different test facilities will be planned to provide necessary full scale component development. One facility will consist of a minimum number of full scale envelope components which permit investigation of the cleanability of interacting envelopes. Another facility will be full size capacity to investigate the introduction of sorbent/precoat into the gas stream and the effect of prototype connecting ductwork configuration upon the uniformity of particulate distribution to the envelopes.

- SUBTASK 3.2:** Component Fabrication and Modification: A preliminary design of the most favorable design of the assumed envelope filter control concept will be projected to the size and space constraints of installation on a locomotive. From this preliminary design activity, it will be possible to determine the size of the full size capacity cold flow test facility, as well as the limited scope of modular units which will be representative of the operation and performance of a full size collector system. Consideration will be given to permissible design changes which may be explored if an initial design concept is not satisfactory. The cold flow test facilities will be designed, procured and installed for cold flow testing in GEESI Laboratory.
- SUBTASK 3.3:** Test Implementation and Data Analysis: Testing of full scale assumed envelope filter components will permit variation of operating conditions to allow determination of final collector system design projection for full size engine operation.
- SUBTASK 3.4:** Component Development Test Program Topical Report: A report of Task 3 activities will be prepared and submitted.

TASK 4.0: Integrated System Development and Tests, Design Integrated System:

SUBTASK 4.1: Design full scale emission control system for operation service with full size CWM engine in GETS test cell. Control system will be assumed envelope filter candidate concept determined by pilot scale in 2.2.3, .4, .5, and .6; and optimized full size components in 3.2 and 3.3. Collector system will take engine exhaust from engine, downstream of pressure reduction valve simulating turbocharger, and return treated gas to existing test cell exhaust silencer and stack. Collector equipment will, because of size and complexity, be installed exterior to the test cell building. The design of the collector configuration will be in accordance with the eventual space restraints of locomotive installation. All components of eventual locomotive installation will be included in the test cell engine collector system design. However, the position of auxiliary equipment components may be relocated from the configuration required for locomotive installation, to permit more convenient access to equipment for experimental procedures.

For purposes of estimating Engineering Design and Procurement of Equipment expenses, reference the attached GEESI preliminary full size collector system GA drawings S9513/GA830 & 840 for envelope filter collector system and S9513/GA810 for granular bed filter collector system.

SUBTASK 4.2: Modify Design of Integrated System: Design of installed collector system will be modified, as required, in accordance with results of ongoing component development (design) and ongoing determination of component materials and auxiliary equipment.

TASK 5.0: Integrated System Development and Tests, Test Integrated System:

- SUBTASK 5.1: Integrated System Test Plan:** Prepare plan for operation and testing of selected candidate emission control system. Plan shall include variation of hardware which is yet uncommitted for the full size equipment. Plan shall also include variation of operating conditions of auxiliary equipment as well as reagent consumables. Test plan shall be consistent with more facilitated test diagnostics permitted by stationary engine mode, contrasted with eventual locomotive operation.
- SUBTASK 5.2: Integrated System Preparation:** Procure and install emission control system equipment designed in 5.1. GEESI activity shall include an installation plan which will be executed by an outside contractor to GEESI. GEESI project team and/or GEESI construction supervisor shall oversee the installation activity.
- SUBTASK 5.3: Integrated System Commissioning Tests:** GEESI project team personnel shall perform necessary calibration of instrumentation and shakedown operation of system equipment.
- SUBTASK 5.4: Integrated System Test Implementation and Data Analysis:** GEESI project team will execute Test Plan 5.1, including alteration of system component hardware and auxiliary equipment operating conditions.

In consideration of expected large size of variable system equipment hardware, it may be necessary to utilize outside contractor services to perform equipment hardware changes. Execution of test plan will include evaluation of test results and development of a test report which will be utilized to conclude final system design to be installed in commercial operating locomotive.

TASK 6.0: Commercial System Design Evaluation and Program Assessment:

SUBTASK 6.1: Subsystem Optimization Test Plan: Design feedback from Task 5.4 will be utilized to perform any final modifications to the stationary collector test facility before installing equipment in operating locomotive. Design feedback shall also determine operating conditions for auxiliary equipment for operating locomotive operation. A test plan will be developed to determine how emission control equipment will be operated during locomotive operation.

SUBTASK 6.2: Subsystem Operation: System equipment hardware modifications determined by 6.1 will be procured and installed in the emissions control system prior to installation of system on operating locomotive. Equipment will be operated in accordance with 6.1 plan during operation of locomotive at GETS test track. Results of operating locomotive test operation of emission control system will be evaluated and reported.

SUBTASK 6.3: Commercial System: Conclusions of operating locomotive operation of emission control system will be utilized to refine design of system projected for commercial operation. Commercialization of design will include generation of performance characteristics, reliability, maintenance, operating and capital costs, and waste/off product disposal/regeneration. A final report will define commercial implementation strategy and final design documentation, including design and fabrication drawings, bills of material, and operation and maintenance manual.

TASK 7.0: Program Management: This program task is being added to the original program work statement. GEESI activity will be tracked for the purpose of this BOE procedure and for other program activity, such as the generation of required status and financial reports, but not for technical reports.

COAL FUEL DIESEL TECHNOLOGY DEVELOPMENT

DOE/GETS CONTRACT S9513

CEEST DETAIL. PROGRAM ACTIVITY SCHEDULE TO COMPLETE PROGRAM

(REVISED 10/30/90)

[illegible]

**COAL FUEL DIESEL TECHNOLOGY DEVELOPMENT
DOE/GETS CONTRACT S9513
GEESI DETAIL PROGRAM ACTIVITY SCHEDULE TO COMPLETE PROGRAM
(REVISED 10/30/90)**

[illegible]

**COAL FUEL DIESEL TECHNOLOGY DEVELOPMENT
DOE/GETS CONTRACT S9513
GEESI DETAIL PROGRAM ACTIVITY SCHEDULE TO COMPLETE PROGRAM
(REVISED 10/30/90)**

[illegible]

COAL FUEL DIESEL TECHNOLOGY DEVELOPMENT
DOE/GETS CONTRACT S9513
GEESI DETAIL PROGRAM ACTIVITY SCHEDULE TO COMPLETE PROGRAM
(REVISED 10/30/90)

ACTIVITY	TASK	1990				1991				1992				1993			
		1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q
COMP. DEV. MODULAR ASSUME EF TEST	3.3						X X										
COMP. DEV. FULL SIZE ASSUME EF DESIGN	3.2						X										
COMP. DEV. FULL SIZE ASSUME EF PROCURE	3.2						XX										
COMP. DEV. FULL SIZE ASSUME EF INSTALL	3.2							X									
COMP. DEV. FULL SIZE ASSUME EF TEST	3.3							XX									
COMP. DEV. TOPICAL REPORT	3.4							XX	XXX								
INTEGRATED SYSTEM DESIGN:	4.0																
FINAL CANDIDATE SYSTEM DESIGN	4.1 4.2							XX	XX								
INTEGRATED SYSTEM TEST:	5.0																
INTEGRATED SYSTEM TEST PLAN	5.1							XX	XX								
GETS FS ENG. CELL FINAL SYSTEM PROCURE	5.2								X	XXX							
GETS FS ENG. CELL FINAL SYSTEM INSTALL	5.2										XX						

COAL FUEL DIESEL TECHNOLOGY DEVELOPMENT
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GEESI DETAIL PROGRAM ACTIVITY SCHEDULE TO COMPLETE PROGRAM
(REVISED 10/30/90)

ACTIVITY	TASK	1990				1991				1992				1993			
		1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q
GETS FS ENG. CELL FINAL SYSTEM TEST	5.3 5.4										X	XXX	XX				
COMMERCIAL SYSTEM DESIGN EVALUATION AND PROGRAM ASSESSMENT	6.0																
TEST PLAN	6.1											XXX	XXX	X			
INSTALL FINAL SYSTEM ON ROLLING LOCOMOTIVE	6.2												X	X			
FINAL SYSTEM ON ROLLING LOCOMOTIVE TEST	6.2													XX	XXX	XXX	XXX
FINAL SYSTEM ON ROLLING LOCOMOTIVE REPORT	6.3													XX	XXX	XXX	XXX

TAB 1

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**DOE/GETS TOPICAL REPORT
CHAPTER 1**

CHAPTER 1

Commensurate with Task 1, Conceptual Commercial System Design and Research Definition.

Task 1

Slipstream testing of Emissions Control concepts utilizing GETS engine laboratory single cylinder CWS fuel research diesel engine.

Test Facility

This phase of the program was initially devoted to investigation of various Emissions Control concepts such as barrier filtration, granular bed filtration, and cyclone collection. The testing facility was a small slipstream of approximately 10 ACFM from a CWS fuel engine. The test facility was initially installed to provide a diagnostics site for determination of emissions characteristics during evolution of the diesel engine design for operation with CWS fuel. The facility was first constructed and tested upstream of a back pressure gas flow control valve, simulating operation on engine exhaust gas upstream of the engine turbocharger.

After completion of the Emissions and Control Concept Characterization phases of the program, the test facility use progressed to further investigation of barrier filtration techniques. All barrier filtration testing was performed using the conventional candle type configuration for the filter media.

A previous topical report, "Characterization and Control of Exhaust Gas from Diesel Engine Firing Coal Water Mixture", by E. Samuel, E. Gal, M. Mengel and M. Arnold in March 1990 discussed early characterization of emissions and early investigation of emissions control concepts. This work also included the evolution of the preferred barrier filtration control concept, including the use of precoating of the filter media with sorbent particulate materials for the dual purpose of reaction with exhaust gas constituents and enhanced cleanability of the filter media. A recommendation of the previous topical report was a test plan for 10 additional slipstream candle filter tests to investigate a number of new and different filter media and precoat particulate materials. This test plan is enclosed in Appendix 1 as Figure 1-1.

The slipstream test facility is illustrated by Figure 1-2. However, the test facility was modified by relocation of the gas flow control valve to a location upstream of the control devices being tested. The purpose of this modification was to permit operation of the candle filter device at a positive pressure close to atmospheric pressure, thereby permitting more

**DOE/GETS TOPICAL REPORT
CHAPTER 1**

effective reverse air pulse on-line cleaning of the candle filter. An additional modification was the addition of provision for injection of ammonia at a location upstream of the candle filter for investigation of NO_x reduction when using Copper Oxide precoat/sorbent particulate material.

Discussion of Test Results

A total of eight (8) additional candle filter tests were performed. Table 1-1 summarizes the composition of the filter media, precoat/sorbent particulate, and other test operating conditions. Referenced test results are included in Appendix 1.

Test TS 25 was conducted using a Fluid Dynamics Inconel fiber filter media candle filter. The filter was precoated with a particulate consisting of a coating of Copper Oxide on Alumina Powder prior to the start of the test. Test duration was 65 minutes. The first 40 minutes of testing was performed at a gas flow of 4.5 ACFM corresponding to a filtration velocity of 10 FPM. During this operation, as illustrated by Figures 1-3, 1-4 and 1-5, candle filter pressure drop increased from 9 to 16 IWG. Filter outlet SO₂ concentration achieved during this operation was approximately 100²PPMV, which represented a reduction of 60% based upon an assumed filter inlet concentration of 250 PPMV. Uncontrolled filter inlet NO_x concentration was 550 PPMV.

At 20 minutes of operation, ammonia injection was started at a stoichiometric ratio of 50% to 70%. NO_x concentration was reduced to as low as 220 PPMV, representing a 60% reduction.

At 40 minutes of operation, gas flow was increased to 8.2 ACFM corresponding to a filtration velocity of 17 FPM. This caused an immediate increase of candle filter pressure drop to 35 IWG. As operation continued, pressure drop proceeded to increase to 43 IWG. During this time of operation, SO₂ concentration remained constant at 100 PPMV, but NO_x concentration increased to 375 PPMV, corresponding to a decreased reduction^x of 32% as a consequence of reduced ammonia stoichiometry.

An initial cleaning of the candle filter was performed using 90 PSIG air at 50 minutes of test operation with a filter pressure drop of 43 IWG. An effective cleandown pressure drop of 13 IWG was obtained. However, the cleaning removed the precoating of Copper Oxide sorbent as well as the CWS fuel ash. As a result, SO₂ concentration increased to 130 PPMV, or a removal of 48%, and NO_x concentration increased to 530 PPMV, corresponding to essentially nil removal.

Two additional cleanings were performed at test times of 57 minutes and 62 minutes, initiated at a 20 IWG pressure drop. Both cleanings produced an 11 IWG cleandown pressure drop. Each cleaning also produced further increases of SO₂ and NO_x concentrations of 150 PPMV and 550 PPMV, respectively.

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Figures 1-6 and 1-7 illustrate additional tests of O_2 , CO_2 , CO, and Hydrocarbons, HC, resulting in levels of O_2 and CO_2 concentrations remaining essentially constant during the entire test at 12.5% volume and 7% volume, respectively. Short duration increased concentration spikes of O_2 and decreased concentration spikes of CO_2 are indicative of the introduction of O_2 in the air for filter cleaning and the consequent relative reduction of CO_2 concentration.

HC concentration remained constant at 70 PPMV during the time of operation until the filter was cleaned. When copper oxide sorbent was removed by cleaning, HC concentration increased to 110 PPMV. CO concentration at the start of the test was 100 PPMV and increased continuously to a concentration level of 380 PPMV by the end of the test. Decreased concentration spikes occurred for HC and CO, as well as for SO_2 and NO_x , as a result of filter cleaning.

Test TS 26 was conducted using a filter media consisting of a woven ceramic material supplied by vendor 3M. The filter media was supported by an internal perforated metal cylinder to permit operation with particulate on the external surface. The filter was precoated prior to the start of the test with Neutralite supplied by vendor BHA, a fine powder of aluminum silicate used for precoating of fabric filter baghouses, to enhance the cleanability of the CWS ash, but not to provide any sorbent properties. There was no injection of ammonia during this test since there was no sorbent characteristic to be evaluated.

During 18 minutes of operation (test time 37 minutes to test time 55 minutes) at an operation filtration velocity of 5 FPM, filter pressure drop increased very slowly from 8 to 9 IWG. During this time of operation, NO_x and SO_2 concentrations were constant at values of 770 PPMV and 150 PPMV, respectively. Also, concentrations of O_2 , CO_2 , CO, and HC were constant at values of 13% volume, 6.5% volume, 160 PPMV, and 240 PPMV, respectively.

At test time 55 minutes, gas flow was increased to a filtration velocity of 8.5 FPM resulting in a filter pressure drop increase to 16 IWG and an ongoing slow rate increase. All gas concentration measurements were unaffected. The test was terminated at test time 61 minutes because of a diesel engine malfunction before there was an opportunity for filter cleaning.

Test TS 27 was performed using a sintered stainless steel 5 micron porosity candle filter supplied by vendor Michigan Dynamics. The filter was precoated with Copper Oxide/Alumina particulate. Stabilized gas flow operation began at test time 29 minutes at a gas flow of 10 ACFM, a filtration velocity of 5 FPM, and a candle filter pressure drop of 11.5 IWG.

From test time 29 minutes until time 45 minutes, candle filter pressure drop increased from 11.5 to 19 IWG. During this time of operation, O_2 and CO_2 concentrations remained constant at 13% volume and 7% volume, respectively.

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Also, NO_x and HC concentrations were constant at values of 660 PPMV and 80 PPMV, respectively, but CO and SO_2 concentrations sustained a gradual increase from 120 to 160 PPMV and 30 to 40 PPMV, respectively. This filter outlet SO_2 concentration represented a reduction of 88% to 84%, based upon an assumed 250 PPMV filter inlet concentration.

An initial cleaning of the filter was performed at test time 45 minutes, at a filter pressure drop of 19 IWG. Cleandown was to a pressure drop of 5 IWG. As a result of the removal of the Copper Oxide sorbent from the filter, SO_2 concentration increased to 140 PPMV, representing a decreased SO_2 reduction of 44%. Removal of the sorbent also resulted in increased CO concentrations to 220 PPMV and increased HC concentrations to 180 PPMV.

Additional cleanings of the filter were performed at time 51 minutes at an initiation pressure drop of 11 IWG and a cleandown pressure drop of 5 IWG, and, again, at time 57 minutes at an initiation 16 IWG and cleandown 8 IWG. Neither of the latter two cleanings resulted in any significant change of filter outlet gas composition characteristics.

During early test operation, from time 10 minutes to time 17 minutes, there were 41 standard cc/minute of Ammonia injection into 4.0 ACFM gas flow which corresponded to an Ammonia stoichiometric ratio of 50%. During this Ammonia injection, filter outlet NO_x concentration was reduced to 320 PPMV, representing a reduction of $\times 52\%$.

Test TS 28 was conducted using a rigid ceramic candle filter supplied by Refractron Technology Corp. This filter was coated with Copper Oxide coated Alumina powder. Stabilized gas flow operation began at time 36 minutes at a gas flow of 10 ACFM, a filtration velocity of 15 FPM, and a filter pressure drop of 24 IWG. From time 36 minutes to time 61 minutes, filter pressure drop increased from 24 IWG to 40 IWG. During this time period of operation, O_2 , CO_2 , and HC concentrations were constant at 13.5% volume, 6.5% volume and 145 PPMV, respectively. However, SO_2 concentration gradually increased from 105 PPMV to 120 PPMV, and CO concentration gradually increased from 155 PPMV to 170 PPMV.

At the start of the test, NO_x concentration at the inlet to the filter was 750 PPMV. Ammonia injection^x into the gas flow was started at time 10 minutes and continued until time 25 minutes at a rate of 40 standard cc/minute into variable gas flow rates. At time 25 minutes, Ammonia flow was increased to 80 standard cc/minute which was continued until time 64 minutes. This latter Ammonia flow condition into 10 ACFM of gas resulted in an Ammonia stoichiometric ratio of 87%. Under this operating condition, the resulting filter outlet NO_x concentration was constant at 590 PPMV and represented a NO_x reduction of $\times 21\%$.

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An initial cleaning of the filter was performed at time 61 minutes at a pressure drop of 40 IWG. A cleandown pressure drop of 5 IWG was obtained. After this initial cleaning, SO_2 concentration increased from 120 PPMV to 140 PPMV, NO_x concentration increased from 590 PPMV to 700 PPMV, and HC concentration increased from 145 PPMV to 175 PPMV as a result of removal of Copper Oxide sorbent as well as removal of Copper Sulfate, catalyst for NO_x reduction. For unknown reasons, CO concentration decreased from 170 PPMV to 160 PPMV.

Another cleaning was performed at time 70 minutes from an initiation pressure drop of 26 IWG to a cleandown pressure drop of 6 IWG. This second cleaning resulted in continued increases of SO_2 and HC concentrations and a continued reduction of CO concentration. Another operating change was a reduction of the Ammonia injection rate from 80 to 7 standard cc/minute at time 64 minutes. While the former operating condition represented an 87% Ammonia stoichiometric ratio, the latter stoichiometric ratio condition was only 8%. This significant reduction of Ammonia stoichiometry resulted in increased filter outlet NO_x concentration after time 64 minutes.

Test TS 29 was similar to Test TS 27, except that 10 micron porosity Michigan Dynamics sintered stainless steel filter media was used for the candle filter. Precoating of the filter was again performed using Copper Oxide coating on Alumina powder. Stable gas flow operation began at time 45 minutes at a gas flow of 9.6 ACFM and a filter pressure drop of 23 IWG. During operation, until time 53 minutes when an initial cleaning of the filter was performed, filter pressure drop increased from 23 to 28 IWG. During this time of operation, O_2 and CO_2 concentrations were constant at 12.5% and 6.5%, respectively. SO_2 , HC, and CO concentrations were also constant at 100 PPMV, 140 PPMV, and 150 PPMV, respectively. However, it is noteworthy that each of these gases had occurred at much reduced concentrations earlier in the test before gas flow was stabilized. There is good reason to believe that much of the sorbent had already become reacted before stabilized gas flow was established.

At the start of the test, NO_x concentration at the filter inlet was 700 PPMV. First injection of Ammonia was started at time 10 minutes at a rate of 40 standard cc/minute into a gas flow of 3.8 ACFM. This operation represented an Ammonia stoichiometric ratio of 121%, and resulted in a filter outlet NO_x concentration of 340 PPMV and a NO_x reduction of 51%. When Ammonia injection was increased to 80 standard cc/minute into 9.6 ACFM gas flow, the stoichiometric ratio was decreased to 95% and filter outlet NO_x concentration increased to 550 PPMV. This operation was constant from time 45 minutes to time 53 minutes and represented a NO_x reduction of 21% before the initial cleaning of the filter.

The initial cleaning of the filter was performed at time 53 minutes at an initiation filter pressure drop of 28 IWG and a cleandown pressure drop of 5 IWG. As a result of this initial cleaning, filter outlet SO_2 concentration increased from 100 PPMV to 140 PPMV, HC concentration increased from 140 PPMV to 200 PPMV, and NO_x concentration increased from 550 PPMV to 700 PPMV. This final NO_x concentration represented a failure to remove any NO_x .

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Additional cleanings of the filter were performed at time 63 minutes from a 20 IWG initiation to a 7.5 IWG cleandown pressure drop, and at time 69 minutes from a 23.5 IWG initiation to a 15 IWG cleandown pressure drop. Each of these cleanings had no significant effect upon SO_2 , HC, and CO concentrations at the filter outlet. However, reduction of Ammonia injection at time 60 minutes, from 80 standard cc/minute to 40 and then to 7 standard cc/minute, resulted in further increase of filter outlet NO_x from 700 to 750 PPMV.

Test TS 30 utilized precoating of a Fluid Dynamics stainless steel fiber filter media candle filter with 150 grams of Copper Oxide coated Alumina which was regenerated and re-coated after previous test use. Pre-test exhaust gas composition was 200 PPMV SO_2 , 500-600 PPMV NO_x , 650 PPMV CO, 250 PPMV HC, 6.5% volume CO_2 , and 13% volume O_2 . Initial exhaust gas operation was at a rate of 6 ACFM² corresponding to a filtration velocity of 9 FPM at 700 F temperature. During initial operation, SO_2 concentration was reduced from 200 to 12 PPMV, CO concentration was reduced from 650 to 120 PPMV, and HC concentration was reduced from 250 to 50 PPMV. CO_2 and O_2 concentrations were, however, unchanged.

Candle filter pressure drop during initial operation was 8 IWG, and the pressure drop of the absolute filter located downstream of the test candle filter was 6 IWG.

80 standard cc/minute of Ammonia injection was started at test time 18 minutes. NO_x concentration was quickly reduced from 500 - 600 PPMV to 50 PPMV. At the same time, SO_2 concentration was unchanged at 12 PPMV, as was the HC concentration at 50 PPMV, as well as the CO_2 and O_2 concentrations. However, CO concentration began a gradual increase from the previous 120 PPMV minimum concentration.

During 30 minutes of operation at 6 ACFM gas flow, candle filter pressure drop increased from 8 IWG to 14 IWG. Also, during this time of operation, absolute filter pressure drop remained unchanged at 6 IWG indicating complete collection of exhaust gas particulate by the test candle filter.

At time 30 minutes, gas flow was increased to 11 ACFM, corresponding to a filtration velocity of 16 FPM. When gas flow increased, candle filter pressure drop immediately increased to 35 IWG, and absolute filter pressure drop increased to 13 IWG. Simultaneously, filter outlet NO_x concentration increased from 50 PPMV to 150 - 200 PPMV as a result of reduced time for the NO_x reduction reaction to occur. In addition, although SO_2 , HC, CO_2 , and O_2 concentrations were unchanged, CO concentration further increased to a concentration of 250 PPMV.

Operation at 11 ACFM gas flow was maintained for 13 minutes. During this operation, candle filter pressure drop further increased to 40 IWG, but absolute filter pressure drop was unchanged, again indicating complete collection of exhaust particulate by the candle filter. All other gas concentrations were unchanged, except for CO which continued to increase to a concentration of 380 PPMV.

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Since the candle filter pressure drop of 40 IWG was greater than a planned 30 IWG test operating condition, gas flow was reduced back to 6 ACFM at test time 45 minutes. At this operating condition, candle filter pressure drop decreased to 22 IWG, which was greater than the pre-gas flow excursion value of 14 IWG. However, absolute filter pressure drop returned exactly to the 6 IWG pre-gas flow excursion value. Also, filter outlet NO_x concentration decreased from 150-200 PPMV to 30 PPMV, which was less than the pre-excursion value of 50 PPMV. Other gas compositions were unchanged, except for CO which decreased to 270 PPMV.

Test operation was then constant for 28 minutes until time 70 minutes. During this time, all gas concentrations were unchanged. This included the candle filter pressure drop which was constant at 22 IWG. It is not understood why this pressure drop did not increase with time.

At test time 72 minutes, the candle filter was cleaned by a reverse flow pulse of 90 PSIG air. When operation was resumed at 6 ACFM, candle filter pressure drop was reduced from 22 IWG to 6 IWG. However, since filter cleaning also removed the sorbent material, gas concentrations at the filter outlet subsequent to the cleaning were affected. NO_x concentration increased from 30 to 300 PPMV and SO_2 concentration increased from 12 to 110 PPMV. Likewise, HC and CO concentrations were increased.

Ammonia injection was terminated at time 88 minutes. This change prompted an increase of filter outlet NO_x concentration to 600 PPMV, similar to the concentration prior to the injection of Ammonia. Although the concentration of SO_2 was not affected, CO concentration decreased and HC concentration increased.

During 30 minutes of operation, before the end of the test and during re-established 6 ACFM gas flow, candle filter pressure drop increased from the cleaned value of 6 IWG to 10 IWG.

Test TS 31 was conducted using a test candle filter composed of 5 micron porosity sintered stainless steel filter media supplied by vendor Michigan Dynamics. This candle filter was identical to the test filter used for previous Test TS 27. Filter precoating was 150 grams of Copper Oxide coated Alumina which was regenerated from previous test use. Approximate pre-test exhaust gas compositions were 200 to 280 PPMV SO_2 , 550 to 750 PPMV NO_x , 250 to 280 PPMV CO, 160 to 210 PPMV HC, 7% volume CO_2 , and 12% volume O_2 .

An initial test gas flow operation of 6 ACFM at 700°F temperature corresponded to a filtration velocity of 6 FPM. During initial operation, filter outlet SO_2 concentration was reduced from 200 - 280 PPMV to 28 PPMV. HC concentration was also reduced to 50 PPMV, and CO concentration was reduced to 130 PPMV. NO_x , CO_2 , and O_2 concentrations were unchanged.

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Initial candle filter pressure drop was 8 IWG, similar to the results of TS 30, but at a reduced filtration velocity. Absolute filter pressure drop was 7 IWG, which was greater than a 6 IWG pressure drop at the start of Test TS 30. This difference is explained by apparently different porosity of the filters used for the individual tests.

Injection of 80 standard cc/minute of Ammonia was started at time 19 minutes. This produced an immediate reduction of filter outlet NO_x concentration from 550 - 750 PPMV to 150 PPMV. SO_2 , HC, CO_2 , and O_2 concentrations were not affected by this injection of Ammonia, but CO concentration experienced a continuing gradual concentration increase from the 130 PPMV minimum attained early in the test.

Operation at a gas flow of 6 ACFM with 80 standard cc/minute of Ammonia injection continued until time 28 minutes. During 22 minutes of operation, candle filter pressure drop increased from 8 IWG to 12 IWG. However, during this same time of operation, absolute filter pressure drop remained constant at 7 IWG indicating collection of all exhaust gas particulate in the candle filter.

At time 28 minutes, gas flow was increased to 11 ACFM corresponding to a filtration velocity of 12 FPM. As a result of this change, there was an immediate increase of candle filter pressure drop to 23 IWG and an immediate increase of absolute filter pressure drop to 14 IWG. Simultaneous with filter pressure drop increases, filter outlet NO_x concentration increased from 150 PPMV to 360 PPMV. At the same time, SO_2^x concentration increased slightly.

As was the procedure for Test TS 30, gas flow was reduced back to 6 ACFM at time 39 minutes. During 10 minutes of operation at 11 ACFM, candle filter pressure drop increased from 23 IWG to 27 IWG. During the same time, absolute filter pressure drop remained constant at 14 IWG. When gas flow was reduced to 6 ACFM, candle filter pressure drop decreased to 15 IWG, which was greater than the 12 IWG pre-gas flow excursion value. However, absolute filter pressure drop decreased exactly to the pre-excursion 7 IWG value. NO_x concentration was also affected by the gas flow change, decreasing to 80 PPMV which was less than a pre-excursion concentration of 150 PPMV.

An initial cleaning of the candle filter was performed at time 50 minutes by a reverse flow pulse of 90 PSIG air. After reestablishment of 6 ACFM filter gas flow, candle filter pressure drop decreased from 15 IWG to 4 IWG. Removal of exhaust particulate again removed sorbent from the filter media, as illustrated by a candle filter pressure drop which was significantly less than occurred at initial test operation when the precoat/sorbent was installed. As a result, NO_x concentration increased greatly from 80 PPMV to 350 PPMV. SO_2 concentration also increased from 50 PPMV to 150 PPMV.

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Operating conditions were held constant for 10 minutes until time 60 minutes. During this period, candle filter pressure drop increased from 4 IWG to 5 IWG.

At time 60 minutes, the candle filter was again cleaned. After this cleaning, candle filter pressure drop experienced a similar 5 IWG to 4 IWG reduction. However, more removal of sorbent from the filter media resulted in a NO_x concentration increase to 500 PPMV.

During an additional 10 minutes of operation, candle filter pressure drop increased from 4 IWG to 6 IWG.

A final cleaning of the candle filter was performed at time 70 minutes. This third cleaning again achieved a cleandown pressure drop of 4 IWG.

The test was terminated soon after the third cleaning of the candle filter at filter outlet gas compositions of 500 PPMV NO_x and 190 PPMV SO_2 . These values compare with concentrations of 450 PPMV NO_x and 120 PPMV SO_2 at the end of Test TS 30. However, the 4 IWG candle filter pressure drop at the end of Test TS 31 was less than the pressure drop of 10 IWG at the end of Test TS 30.

Test TS 32 was conducted using a woven ceramic fiber candle filter supplied by vendor 3M. The candle filter was precoated prior to the start of the test using a combination of regenerated only and regenerated and re-coated Copper Oxide coated Alumina, all of which was recovered from previous tests.

Approximate exhaust gas composition at the start of the test was 650 PPMV NO_x , 250 PPMV SO_2 , 320 PPMV CO, 250 PPMV HC, 13% volume O_2 , and 7% volume CO_2 . All of these values were comparable to operating conditions for Tests TS 30 and TS 31, except for CO which had a greater concentration than in Test TS 30. Initial test operation was with 5 ACFM at 750 F gas temperature. Initial candle filter pressure drop was 7 IWG. This value was comparable to the starting point for Test TS 31. Initial absolute filter pressure drop was 12 IWG. This value was different from the starting value of 7 IWG obtained in Test TS 31. This variation was again indicative of different porosity absolute filters used for each test.

Initial operation caused a reduction of SO_2 concentration from 250 PPMV to 20 PPMV. Also, CO concentration was reduced to 150 PPMV and HC concentration was reduced to 80 PPMV. However, NO_x , CO_2 , and O_2 concentrations were unchanged from pre-test values.

Injection of 80 standard cc/minute of Ammonia was started at time 18 minutes. As a result, NO_x concentration experienced an immediate reduction to an eventual value of 70 PPMV. Other gas concentrations were not affected significantly by the injection of Ammonia, but CO concentration experienced a gradual increase which continued until the end of the test, independent of other test events.

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6 ACFM gas flow was maintained for 32 minutes until time 44 minutes. During this time of operation, candle filter pressure drop increased from 7 IWG to 11 IWG. Also during this time, absolute filter pressure drop increased from 12 IWG to 14 IWG. This characteristic was different from the results of Tests TS 30 and TS 31 which did not show any change of absolute filter pressure drop with time. A conclusion of Test TS 32 was that the candle filter being tested was allowing particulates to escape, and this particulate was being collected in the absolute filter.

A different test procedure for Test TS 32, relative to Tests TS 30 and TS 31, was that no increased gas flow excursion was performed before the candle filter was cleaned. At time 44 minutes, the candle filter was given an initial cleaning. After resuming operation at 6 ACFM gas flow, candle filter pressure drop was reduced to 5 IWG. As was observed in previous Tests TS 30 and TS 31, cleaning of the candle filter removed sorbent, resulting in the NO_x concentration increasing from 70 PPMV to 300 PPMV. Also, SO_2 concentration increased from 70 PPMV to 150 PPMV. HC also experienced a slight sudden increase to 100 PPMV.

After resuming operation at 6 ACFM, the absolute filter showed an immediate increase from 14 IWG to 15 IWG. This event was unique relative to Tests TS 30 and TS 31, and indicated an escape of particulate from the candle filter when it was cleaned and subsequent collection by the absolute filter.

Three additional cleanings of the candle filter were performed after operation intervals of 10 minutes at 6 ACFM gas flow. Each cleaning produced a candle filter pressure drop reduction to 3.5 to 4 IWG after cleaning, and a rapid pressure drop increase to 7 IWG before the next cleaning. During the same time period, absolute filter pressure drop gradually began increasing, reaching 19 IWG by the end of the test. This rate of pressure drop increase was greater than occurred before the initial candle filter cleaning, and indicated continued escape of particulate through the candle filter.

After the initial cleaning of the candle filter and a resulting increased NO_x concentration, the NO_x concentration failed to remain at the elevated concentration, as was the experience in previous Tests TS 30 and TS 31. Instead, NO_x concentration began a rapid decrease to a minimum concentration of 20 PPMV. This minimum occurred between the second and third cleanings of the candle filter. There is no explanation for this behavior. However, after attaining the minimum concentration, NO_x concentration experienced a rapid increase to a concentration of 350 PPMV and remained at that value through the third and fourth cleanings. After completion of the fourth cleaning, NO_x concentration again sustained another unexplained rapid increase to 800 PPMV.

During the series of candle filter cleanings, filter outlet SO_2 concentration remained constant at 150 PPMV.

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At the completion of Test TS 32, candle filter pressure drop was indicating a controlled range between 4 and 7 IWG. This characteristic may be compared to ranges of 7 to 10 IWG and 4 to 6 IWG for Tests TS 30 and TS 31, respectively. Also, at the conclusion of Test TS 32, SO_2 concentration was at a constant value of 150 PPMV, commensurate with values of 120 PPMV and 190 PPMV for Tests TS 30 and TS 31, respectively. However, at the end of Test TS 32 NO_x concentration was 800 PPMV, significantly greater than values of 450 PPMV and 500 PPMV which were observed at the end of Tests TS 30 and TS 31, respectively.

Based upon the results of Tests TS 30, TS 31, and TS 32, it may be concluded that Tests TS 30 and TS 31 use of Fluid Dynamics and Michigan Dynamics stainless steel fiber candle filters produced similar characteristics of the collection of exhaust gas particulates, filter cleanability by a reverse flow pulse of air, and provided a substrate for sorbent removal of SO_2 and NO_x . Test TS 32 use of the 3M ceramic fiber filter media candle filter produced test results which were inferior to the results of Tests TS 30 and TS 31 in regards to particulate collection.

With the completion of Test TS 32, the planned program of single cylinder CWS fuel research diesel engine slipstream testing was considered concluded. Although all test plan tests of filter media type and precoat/sorbent material had not been executed, program direction had already moved in the direction of use of barrier filtration with continuous injection of Copper Oxide coating on Alumina precoat/sorbent particulate. Also, availability of filter media for practical high filtration velocity filter design had directed the design concept to use of large panels of metallic fiber filter media for which several potential vendors had been developed, therefore, making further small slipstream testing unnecessary.

A P P E N D I X 1

TABLE 1-1
SUMMARY OF TEST OPERATING CONDITIONS AND TEST RESULTS
GETS ENGINE LABORATORY SINGLE CYLINDER CNG FUEL RESEARCH DIESEL ENGINE SLIPSTREAM
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FILE SC101

TEST PLAN NUMBER	4	1B	5B	NONE	6B	2B	5B	1C
ACTUAL TEST NUMBER	TS 25	TS 26	TS 27	TS 28	TS 29	TS 30	TS 31	TS 32
TEST DATE	2/6/90	3/13/90	3/14/90	3/15/90	3/16/90	6/4/90	6/6/90	6/8/90
FILTER MEDIA TYPE	FLUID DYNAMICS	3M	HIGH. DYNAMICS	REFRACTRON	HIGH. DYNAMICS	FLUID DYNAMICS	HIGH. DYNAMICS	3M
FILTER MEDIA POROSITY, MICRONS	INCONEL FIBERS	WOVEN CERAMIC	SINTERED S.S.	RIGID CERAMIC	SINTERED S.S.	S.S. FIBERS	SINTERED S.S.	WOVEN CERAMIC
PRECOAT/SORBENT TYPE	N/A	N/A	5	N/A	10	N/A	5	N/A
	Cuo/ALUMINA	NEUTRALITE	Cuo/ALUMINA	Cuo/ALUMINA	Cuo/ALUMINA	Cuo/ALUMINA	Cuo/ALUMINA	Cuo/ALUMINA
						REGEN. AND RECOAT	REGEN.	REGEN. AND RECOAT
PRECOAT/SORBENT SIZE, MICRONS	<104	N/A	<104	>104	< 5 > 104	< 104	< 104	< 104
ADDITIONAL INJECTION USED	YES	NO	YES	YES	YES	YES	YES	YES
ON-LINE CLEANING PERFORMED	YES/3	NO	YES/3	YES/2	YES/3	YES/1	YES/3	YES/4
CANDLE FILTER GAS FLOW, ACFM	8.2	5	10	10	9.6	6, 11	6, 11	6
CANDLE FILTER FILTRATION VELOCITY, FPM	17.3	5	15	15	14	9, 16	6, 12	6
BP CLEANING INITIATION, INB.	43, 20	N/A	19, 11, 18	40, 26	28, 20, 24	22	15, 5, 6	11, 7, 7, 7
CLEANDOWN BP, INB.	13, 11	N/A	5, 5, 8	5, 6	5, 7.5, 15	6	4, 4, 4	5, 3.5, 4, 4

* TABLE 1-1 *

Test Plan for Continuation of Series 2 Testing:

Single candle filter elements of the following 9 filter media shall be characterized with respect to cleanability and coefficient of specific resistance, with and without pre-coat:

1. Woven ceramic fabric from 3M (with limestone precoat - TEST 1)
2. Felt of sintered stainless steel fibers from Fluid Dynamics (with limestone precoat - TEST 2)
3. Felt of Inconel fibers from Fluid Dynamics (without precoat - TEST 3, and with copper oxide precoat - TEST 4)
4. Felt of sintered stainless steel fibers (Type 1) from Michigan Dynamics (with zinc oxide precoat - TEST 5)
5. Felt of sintered stainless steel fibers (Type 2) from Michigan Dynamics (with limestone precoat - TEST 6)
6. Felt of sintered stainless steel fibers from Bekipor (with limestone precoat - TEST 7)
7. Felt of Inconel fibers from Bekipor (with copper oxide precoat - TEST 8)
8. Woven Inconel fabric from Bekipor (with zinc ferrite precoat - TEST 9)
9. Sintered metal medium from Mott (with magnesium oxide precoat - TEST 10)

The filter media shall be characterized for the following conditions:

1. Pre-coat material: powdered limestone, copper oxide, zinc oxide, magnesium oxide and zinc ferrite (nominally 90% - 325 Mesh)
2. The pre-coat material shall be applied off-line prior to exposing the media to CWM exhaust. For each pre-coat condition (no pre-coat, and pre-coat of limestone or copper oxide), the A/C shall be first maintained at 4 ft/min until a pressure drop of 15 in. water across the filter is reached. At this point, the filter shall be subject to an off-line, reverse pulse-jet. Following the cleaning, the gas flow through the filter will be resumed at 4 ft/min for a sufficiently long period to allow recording of the filter pressure drop following cleaning. Soon after this short period, the A/C shall be increased to 7 ft/min, and the procedure of collection and cleaning observed at 4 ft/min, repeated. Following cleaning of the filter cake collected at 7 ft/min, the collection and cleaning procedure shall be repeated for a 10 ft/min A/C.

* FIGURE 1-2 *

**AIR/CLOTH RATIO ACTUAL VS TIME,
700F. FLUID DYNAMIC INCONNEL, PA2-TS25**

PRESS. DROP vs TIME, CuO/Al₂O₃ COATING
700F. FLUID DYNAMIC INCONNEL, FAL-T385

S02/NOx EMISSION vs TIME

NH3 INJECTION, 100gr CuO/AL2O3 COATING

* FIGURE 1-5 *

CO2/O2 EMISSION vs. TIME

HC/CO EMISSION vs TIME

NES INJECTION, 100gr CuO/AL2O3 COATING

* FIGURE 1-7 *

PA2-TS26/3M BAG w/NEUTRALITE PRECOAT
1.0 SQ FT.

PA2-TS26/3M BAG w/NEUTRALITE PRECOAT

* FIGURE 1-9 *

PA2-TS26/3M BAG w/NEUTRALITE PRECOAT

PA2-TS26/3M BAG w/NEUTRALITE PRECOAT

— O₂

— CO₂

* FIGURE 1-11 *

PA2-TS27/M.D.(5m)/S9513-MD2// -104m CuO

* FIGURE 1-12 *

PA2-TS27 / M.D.(5m) / S9513-MD2 / -104m CuO

* FIGURE 1-13 *

PA2-TS27/M.D.(5m)/S9513-MD2// -104m CuO

CO
NOx
HC
SO2

* FIGURE 1-14 *

PA2-TS27 / M.D.(5m) / S9513-MD2 // -104m CuO

— O₂
— CO₂

* FIGURE 1-15 *

PA2-TS27/M.D.(5m)/S9513-MD2// -104m CuO
TOT NH3

* FIGURE 1-16 *

PA2-TS28/REFRACT.(CER.)//+104m CuO-Al2O3

* FIGURE 1-17 *

PA2-TS28/REFRACT.(CER.)//+104m CuO-Al2O

* FIGURE 1-18 *

PA2-TS28/REFRACT.(CER.)//+104m CuO-Al2O3

— CO
— HC
— SO2

PA2-TS28/REFRACT.(CER.)//+104m CuO-Al2O

* FIGURE 1-20 *

PA2-TS28/REFRACT.(CER.)//+104m CuO-Al2O3

— O2
— CO2

* FIGURE 1-21 *

PA2-TS28/REFRACT.(CER.)//+104m CuO-Al2O3
TOT NH3

* FIGURE 1-22 *

PA2-TS29/M.D.(10m)/S9513-MD3/+ -104m Cu

* FIGURE 1-23 *

PA2-TS29/M.D.(10m)/S9513-MD3/+--104m Cu

* FIGURE 1-24 *

PA2-TS29/M.D.(10m)/S9513-MD3/+ -104m Cu

* FIGURE 1-25 *

PA2-TS29/M.D.(10m)/S9513-MD3/+ -104m Cu

— O_2

— CO_2

PA2-TS29/M.D.(10m)/S9513-MD3/+ -104m Cu
TOT NH3

* FIGURE 1-27 *

FLUID DYNAMICS E728 SS CANDLE FILTER TEST TS30-----<150 mesh CuO PRECOAT (REGEN. & RECOAT.) CF GAS FLOW

— CANDLE FILTER
 — ABSOLUTE FILTER

FLUID DYNAMICS E728 SS CANDLE FILTER

TEST TS30-----<150 mesh CuO PRECOAT (REGEN. & RECOAT.)

— SO2
— NOX
— NH3

FLUID DYNAMICS E728 SS CANDLE FILTER

TEST TS30----<150 mesh CuO PRECOAT (REGEN. & RECOAT.)

FLUID DYNAMICS E728 SS CANDLE FILTER

TEST TS30----<150 mesh CuO PRECOAT (REGEN. & RECOAT.)

CO₂

O₂

* FIGURE 1-31 *

MICHIGAN DYNAMICS 5 μ M POROUS. SS CANDLE TEST TS31 ----<150 mesh CuO PRECOAT (REGEN. ONLY) CF GAS FLOW

— CANDLE FILTER
 — ABSOLUTE FILTER

MICHIGAN DYNAMICS 5 μ M POROUS. SS CANDLE

TEST TS31----<150 mesh CuO PRECOAT (REGEN. ONLY)

MICHIGAN DYNAMICS 5 μ M POROUS. SS CANDLE

TEST TS31---<150 mesh CuO PRECOAT (REGEN. ONLY)

* FIGURE 1-34 *

MICHIGAN DYNAMICS 5 μ M POROUS. SS CANDLE
TEST TS31---<150 mesh CuO PRECOAT (REGEN. ONLY) --- CO₂

TEST TS32----<150 mesh CuO PRECOAT (1:1 REGEN. : R&R) ----- CF GAS FLOW

CF GAS FLOW

CANDLE FILTER

ABSOLUTE FILTER

 * FIGURE 1-36 *

3M CERAMIC FIBER CANDLE FILTER

TEST TS32---<150 mesh CuO PRECOAT (1:1 REGEN. : R&R) SO2
 — NOX
 — NH3

3M CERAMIC FIBER CANDLE FILTER

TEST TS32---<150 mesh CuO PRECOAT (1:1 REGEN. : R&R)

HC
CO

3M CERAMIC FIBER CANDLE FILTER

TEST TS32----<150 mesh CuO PRECOAT (1:1 REGEN. : R&R) CO2

— O2

TAB 2

DOE/GETS TOPICAL REPORT
CHAPTER 2A

CHAPTER 2A

Commensurate with Task 2, Emissions Applied R&D.

Task 2.2.1 & 2.2.2

Laboratory cold flow testing of various candidate Emissions Control Concepts, such as:

1. Cyclone Alone
2. Envelope Barrier Type Filter
3. Granular Bed Filter

Test Facilities-General

Laboratory cold flow tests were performed at GEESI Laboratory in Lebanon, PA during the time frame between February 1990 and November 1991. Most significant testing was performed at a maximum ambient temperature air flow of approximately 500 to 700 ACFM. The Emissions Control concept being tested was operated by a forced air flow from a GEESI Laboratory centrifugal blower equipped with a flow control damper located downstream of the blower and controlled by a venturi flow meter located between the blower and control damper, and the Emissions Control system equipment. The discharge from the experimental Emissions Control system was directed to a GEESI Laboratory pulse cleaned type fabric filter acting as a final absolute filter of the experimental Emissions Control system. The capacity of the absolute filter determined the 500 to 700 ACFM size capacity of the experimental Emissions Control equipment.

Initial construction of the test facility used PVC piping for the connecting ductwork between the system operating blower and the experimental Emissions Control equipment and the absolute fabric filter. At an early stage of the testing program, it was noted that the PVC pipe exhibited a static electric charge when operating with air and test particulate. Attempts were made to avoid the static charge by grounding of the pipe. An additional action taken to avoid the static charge was installation of an ionizer device (Exair Ion Cannon) inside the system blower discharge duct. A discussion of the suspected significance of the static charge is included in the Discussion of Test Results section of this report.

Test particulate was introduced into the control system air flow by a screw feeder discharging into the inlet to a small centrifugal blower in order to accomplish deagglomeration of the test particulate. Additional air flow was mixed with the deagglomeration blower discharge to deliver a uniform dispersion of air flow and test particulate to the inlet to the control system.

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CHAPTER 2A**

Test Operating Conditions-General

Previous project tasks which determined the characteristics of CWS fuel diesel engine emissions had characterized engine exhaust gas particulate particle size distribution to be a mass median diameter (MMD) of 3.7 Microns. For the purpose of cold flow Emissions Control system testing, this particulate was simulated by a commercial pulverized silica product (Whittaker, Clark and Daniels, Inc. Silica 21) which had physical properties of 2.55 Specific Gravity and 3.7 Micron MMD. A particle size distribution graph of this test particulate is enclosed in Appendix 2A as Figure 2A-1. This test particulate was fed alone for tests performed for a Cyclone Alone Emissions Control concept at a feed rate of approximately 1 grain/ACF of air flow. This amount of test particulate was determined to be a practical minimum amount to permit gravimetric diagnostics of cyclone particulate collection performance, although it exceeded the 0.25 to 0.35 grains/ACF particulate emissions previously determined to occur in the engine exhaust gas.

For tests of the Envelope Barrier Filter, most were performed simulating the use of precoat/sorbent particulate continuous injection in combination with the engine exhaust ash particulate. The material employed to simulate the precoat/sorbent was Alumina with a particle size distribution MMD of approximately 50 Microns. This was commensurate with the particle size difference perceived to be required to permit separation of the ash constituent from the precoat/sorbent material in order to accomplish regeneration of the precoat/sorbent. Figure 2A-2 in Appendix 2A is a graph of the particle size distribution of the Alumina which was used to represent the substrate for coating with Copper Oxide for use as precoat/sorbent test particulate.

Test Apparatus and Instrumentation - General

At this stage of the program, cold flow testing of Emissions Control concepts was devoted to investigation of control device pressure drop as a function of air flow treatment and particulate collection efficiency. In the case of the cyclone alone concept, which was a device with significantly less than absolute particulate collection efficiency, the particle size of the cyclone effluent was also a test diagnostic. The test facility provided test ports in the Control Device inlet and outlet ductwork. Determination of inlet and escape particulate concentration was performed by procedures similar to EPA Methods 2 and 5. For testing of the Cyclone Alone control device, particle size determination was attempted by two procedures.

One successful procedure was accomplished by laboratory analysis of the sampling filter collected particulate sample by Micromeritics Sedigraph Model 5000D Particle Size Analyzer. The other procedure attempted was by use of Malvern Mach 2 Aerosizer. Although this instrument had produced fair agreement with analysis performed by the Sedigraph, when used as a laboratory device for analysis of bulk samples. However, when operated as an insitu analyzer, the results were quite ambiguous. It was these apparently

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ambiguous results which raised the suspicion of particulate agglomeration caused by static electric charge in the PVC ductwork. However, the particle size analyses performed by the Sedigraph produced quite classical cyclone performance Fractional Grade Efficiency characteristics. Consequently, the evaluation of test results using the Malvern Aerosizer were abandoned.

Emissions Control System Concepts Investigated

Cyclone Alone Test Facility

The Cyclone Alone concept was investigated, although it was recognized to be inadequate for absolute particulate collection purposes for other reasons:

1. For use upstream of the diesel engine turbocharger, for protection of the turbocharger from CWS ash particulate erosion.
2. As a first stage collector upstream of a Granular Bed Filter (GBF) device, to protect the GBF from fouling by the major concentration of CWS ash.

The complication of applying a cyclone to the CWS Fuel Diesel Engine Locomotive application was a need to the best compromise of Particulate Collection Performance v. Pressure Drop and Space Occupied by the device.

The GEESI convention of expression of these characteristics is by the term Cyclone Series which is a numerical expression of the Cyclone Diameter Area divided by the Cyclone Inlet Area. Commercial GEESI cyclone series have identities ranging between 350 and 750. These numerical values correspond to area ratios of 3.5 and 7.5, respectively. The higher the series number, the larger the cyclone in height as well as diameter for the quantity of gas flow throughput. Also, because of other internal dimensional characteristics, such as the diameter of the vortex finder outlet, the pressure drop characteristic is also a direct function of the series number. Conversely, the lower the cyclone series number, the greater the gas flow throughput for the size of the cyclone and the lower the pressure drop characteristic.

Early in project planning for testing of cyclones, there was consideration given to testing a variety of cyclone series configurations, including High Series Number/Ultra High Efficiency Characteristic configurations. However, it became apparent that for installation downstream of the diesel engine turbocharger, the configuration most likely worth investigation, driven by space/capacity considerations, was a Low Series Number/Minimum Space Requirement/Lower Pressure Drop Characteristic/Lower Efficiency Characteristic configuration. The cyclone configuration described by these requirements

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was a Series 200 Cyclone. Refinements of the basic cyclone configuration and operation of the cyclone at a high inlet velocity of 100 FPS were planned enhancements to compensate for an inherent deficient collection efficiency characteristic.

The basic cyclone designed for the testing program is described by GEESI Drawing S9513/MD 800, and is enclosed in Appendix 2A. The planned performance enhancements included in this design were:

1. Transitional shape of cyclone inlet scroll which was planned to more effectively move particles into the collection vortex.
2. 225 degree inlet scroll.
3. Use of vortex breaker in disengaging hopper.

The 6.5 inch diameter cyclone size, when operated at 100 FPS inlet velocity, resulted in a desired cyclone gas flow of 700 ACFM. The described enhancement features are identified by the prefix "JM" before the cyclone series number.

Variations of the basic cyclone design are illustrated by GEESI Drawing S9513/MD 801, enclosed in Appendix 2A. Variation identified by prefix "Modified JM" has the same inlet area and the same 225 degree inlet scroll as the basic "JM" configuration. The difference between the "Modified JM" and the basic "JM" is that the "Modified JM" has a flat inlet roof and the entire transition shape change on the bottom of the inlet scroll.

Variation identified by the prefix "CG" is a replication of the commercial GEESI cyclone design and is described by a conventional 180 degree inlet scroll without any transitional shape change except for a downward expansion of the bottom of the inlet for the entire 180 degrees of the inlet scroll.

Although each of the three cyclone configuration variations required separate custom fabrication of the cyclone cylinder, each configuration used an identical cyclone cone component and used identical vortex finder diameter and penetration length dimensions.

Cyclone Test Procedure

Evaluation of cyclone collection performance was performed using the Alpha-Beta procedure, where Alpha is an indicator of the cyclone Fractional Grade efficiency characteristic and Beta is a function of cyclone inlet particulate particle size distribution. Collection efficiency of the cyclone can be determined by:

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CHAPTER 2A**

$$\text{Collection Efficiency} = \text{Alpha}/(\text{Alpha}+\text{Beta})$$

Where, Alpha is defined by the equation:

$$E(d) = 1 - e^{-\text{Alpha} \cdot d} \quad \text{or,} \quad \text{Alpha} = \ln(1 - E(d)) / (-d)$$

$E(d)$ = Collection Efficiency of particle of diameter d microns.

In theory, the value of Alpha is a constant value independent of d . However, to adjust for some failure of actual test results to follow theory, a test Alpha value was determined as a weighted average using the cyclone inlet particle size distribution as the weighting factor.

Particulate particle size distribution factor Beta is defined by the equation:

$$Z(d) = e^{-\text{Beta} \cdot d} \quad \text{or,} \quad \text{Beta} = \ln(1/Z(d)) / d$$

$Z(d)$ = cumulative fraction by weight having a size larger than d microns.

In theory, a log-normal distribution of particle size will produce a constant value of Beta, independent of d . However, some failure of actual test results to follow theory was accounted for by a test Beta value weighted in terms of the cyclone inlet particle size distribution.

A typical example calculation of a computer spread sheet evaluation of a cyclone test is included in Appendix 2A, as Figure 2A-3A through J.

Figure 2A-4 through 2A-10 are typical graphs of particle size distribution and fractional grade efficiency test results as determined by various computation processors using Sedigraph and Malvern Test Data.

Cyclone pressure drop was measured as the Static Pressure difference from the cyclone inlet (at the cyclone inlet velocity), to the cyclone outlet. Measurements at the cyclone outlet were performed at two locations: 1) at a location which included the cyclonic gas flow in the cyclone outlet duct and 2) at a location downstream of a gas flow straightener where spin was eliminated. Cyclone pressure drop characteristic was determined as a function of cyclone inlet Velocity Pressure, IWG, in the equation:

$$dSP = K \cdot VP(ci)$$

A cyclone pressure drop characteristic was also determined between the cyclone inlet and the cyclone particulate collection hopper. Although of no particular importance to this specific program, this information is sometimes of interest when it is necessary to remove collected particulate from the hopper while the cyclone is in operation.

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Test data determined by cyclone testing was as follows:

- Cyclone air flow as measured by venturi flow meter
- Cyclone air flow density, lb/cuft
- Cyclone inlet test particulate feed, weight
- Cyclone inlet isokinetic sample, weight
- Cyclone catch, weight
- Cyclone escape isokinetic sample, weight
- Cyclone inlet test particulate feed particle size distribution by Sedigraph
- Cyclone inlet test particulate feed particle size distribution by Malvern
- Cyclone inlet isokinetic sample particle size distribution by Sedigraph
- Cyclone inlet isokinetic sample particle size distribution by Malvern
- Cyclone catch particle size distribution by Sedigraph
- Cyclone catch particle size distribution by Malvern
- Cyclone escape isokinetic sample particle size distribution by Sedigraph
- Cyclone escape isokinetic sample particle size distribution by Malvern
- Cyclone dSP, inlet to outlet, with spin
- Cyclone dSP, inlet to outlet, without spin
- Cyclone dSP, inlet to hopper

Cyclone test results determined by computer spread sheet calculations were as follows:

- Cyclone test inlet duct velocity, FPS, and Velocity Pressure, IWG
- Cyclone dSP factor, K, inlet to outlet, with spin
- Cyclone dSP factor, K, inlet to outlet, without spin
- Cyclone dSP factor, K, inlet to hopper
- Cyclone inlet test particulate feed concentration, grains/cuft
- Cyclone Collection Efficiency by inlet feed and catch weights
- Cyclone Collection Efficiency by inlet and escape concentration sampling. This value was used for Fractional Efficiency calculations.
- Weighted average Alpha
- Weighted average Beta of cyclone inlet feed
- Weighted average Beta calculated for cyclone inlet
- Calculated cyclone Collection Efficiency, from weighted average Alpha and weighted average Beta

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Test data and calculated test results were projected to operation with typical CWS fuel diesel engine particulate particle size distribution weighted Beta as follows:

Cyclone Collection Efficiency by test fractional efficiency
and typical cyclone inlet particle size distribution.
Cyclone Collection Efficiency by test Alpha and typical
cyclone inlet Beta.

Test data and calculated test results were also projected to CWS fuel diesel engine operation at operating conditions of:

700 ACFM engine exhaust gas flow per cyclone
Exhaust gas temperature = 700 F
Adjusted cyclone size for 100 FPM cyclone inlet velocity
CWS ash particulate SG=1.55 < test particulate SG=2.55

This projection was performed by adjustment of the test Alpha value for changed operating conditions using GEESI standards for Cyclone Performance Factors. The composite of the adjusted Alpha factor, in combination with the typical CWS fuel diesel engine Beta factor, were used to determine:

Cyclone Collection Efficiency, based upon test determination of cyclone performance Alpha factor, and typical operating CWS fuel diesel engine exhaust particulate, projected to expected CWS fuel diesel engine gas and particulate operating conditions.

Test plan

Figures 2A-11A, B and C, 2A-12A, B and C, and 2A-13A, B and C in Appendix 2A are a tabulation summary of all cyclone tests performed, including Cyclone configurations tested and test operating conditions. This tabulation also includes a summary of pertinent test results which lead to the determination of test results conclusions.

Test numbers 002 through 008 were all performed with the "CG" cyclone configuration using 3.7 micron MMD silica test particulate at a cyclone inlet particulate concentration of approximately 1 grain/acf. All tests, except Tests 005 and 006, were performed at approximately 680 ACFM, and Tests 005 and 006 were performed at approximately 430 ACFM. Another test configuration variable was the location of the cyclone hopper vortex breaker. Test locations, as illustrated by Figure 2A-14, were:

Top of disengaging hopper location "T"
Midpoint of disengaging hopper location "M"
Bottom of disengaging hopper location "B"
Bottom of collection hopper-device effectively "OUT"
Top of collection hopper location "TC"

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Tests 008 and 009 were performed using the "JM" cyclone configuration. Because this cyclone had a higher pressure drop characteristic than the previously tested "CG" configuration, the test facility air flow blower was unable to achieve the desired 700 ACFM test condition, and test conditions were limited to approximately 570 ACFM. Test particulate was again with 3.7 Micron MMD silica at a cyclone inlet concentration of approximately 1 grain/acf. Test conditions also considered the location of the cyclone hopper vortex breaker at locations "OUT" and "T".

Tests 011, 012 and 013 were performed using the "Modified JM" cyclone configuration. These tests were again performed using 3.7 Micron MMD silica test particulate at a cyclone inlet concentration of approximately 1 grain/acf. This cyclone configuration also demonstrated a high pressure drop characteristic, similar to the previously tested "JM" type configuration, and air flow was again limited to approximately 570 ACFM. This series of tests also had variable locations of the cyclone hopper vortex breaker at locations "OUT", "T", and "B".

Test series 013, Tests "A", "B", "C", and "D", were all performed with the "Modified JM" cyclone configuration. These tests were performed over a range of test air flow from 367 to 592 ACFM. No test particulate was employed, and the purpose of the tests was to determine if the cyclone pressure drop characteristic was independent of cyclone air flow, in accordance with theory.

Tests 014, 015, and 016, as well as Tests 017, 018, and 019 were all performed using the "Modified JM" cyclone configuration. All tests were performed at a test air flow of approximately 570 ACFM. Injection of test particulate into the cyclone inlet air flow was not performed, but test particulate was placed in the cyclone collection hopper before starting the tests. The purpose of these test was to determine the characteristics of collected particulate as a function of the level of particulate in the collection hopper (0.25, 0.5, and 0.75 of full) and as a function of vortex breaker location ("OUT" and location "B"). Test results were determined by the particulate concentration determined in the cyclone effluent.

Tests 020 and 021 were performed with the "Modified JM" configuration cyclone as an investigation of alternative vortex breaker configuration and location, for the purpose of controlling reentrainment of collected particulate from the cyclone collection hopper. For Test 020, the vortex breaker configuration was a 6 blade cross flow straightener located at the bottom of the disengaging hopper. For Test 021, the flow straightener was modified by the addition of a flat disc to the top surface of the cross, and the device was installed at location corresponding to "T". These tests were performed while test particulate was injected into the cyclone inlet air flow. Other than the vortex breaker configuration, all test operating conditions were similar to previously performed Tests 011 to 013.

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Discussion of Test Results

"CG" Cyclone configuration

Cyclone collection performance was not affected by use or location of vortex breaker.

As expected, test cyclone collection performance was significantly affected by the cyclone inlet velocity operating condition.

Test results ranged between 50% and 65%.

Cyclone pressure drop characteristic was not affected by use or location of vortex breaker. The average pressure drop factor from cyclone inlet to outlet, with spin, was 11.4.

Suspected agglomeration of cyclone inlet test particulate was contradicted by rational particle size distribution test results determined by Sedigraph analyses.

Analysis of test results by Malvern particle size analysis test data was inconclusive. Particle size was consistently much larger than determined by Sedigraph.

When the average of all "CG" configuration cyclone configuration test results were normalized by projection to CWS fuel diesel engine operating conditions, conclusion results were as follows:

700 ACFM exhaust gas flow per cyclone.

Engine exhaust gas temperature = 700 F. Engine exhaust gas density = 0.03427 lb/cuft.

Cyclone inlet velocity = 100 FPS.

Cyclone pressure drop, inlet to outlet, with spin = 11.7 IWG.

CWS fuel diesel engine exhaust particulate with 3.7 micron MMD.

Collection Efficiency of CWS fuel diesel engine particulate = 63.0%.

"JM" Cyclone Configuration

Cyclone collection performance was again not affected by use or location of vortex breaker.

Average test Cyclone Collection Efficiency of approximately 64% at 560 ACFM air flow operating condition was superior to "CG" cyclone performance for operation at a more favorable greater air flow.

Cyclone pressure drop characteristic was not affected by use of or location of vortex breaker, resulting in an average pressure drop factor of 29.2, for cyclone inlet to outlet with spin.

This value was significantly greater than the 11.4 value obtained for the "CG" cyclone configuration.

Test results were again rational for Sedigraph particle size analyses and inconclusive for Malvern particle size analyses.

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Average "JM" cyclone configuration test results were projected to CWS fuel diesel engine operating conditions in the same manner as performed for the "CG" cyclone configuration test results, as follows:

Cyclone diameter = 5.7 inches. (The adjustment from actual 6.5 inch diameter to 5.7 inch diameter was to account for a larger cyclone inlet duct area, where cyclone inlet velocity was measured, than the actual cyclone inlet. Therefore, to evaluate all cyclone configurations on a basis of the same cyclone inlet velocity, the cyclone size was projected to a smaller diameter to achieve the desired 100 FPS inlet velocity.)
Cyclone inlet velocity = 100 FPS.
Cyclone pressure drop, inlet to outlet with spin = 18.0 IWG.
Collection Efficiency of CWS fuel diesel engine exhaust particulate = 74%.

"Modified JM" Cyclone Configuration

Cyclone Collection Efficiency performance was again not affected by the use or location of the vortex breaker.
Average test Cyclone Collection Efficiency of approximately 65% at 570 ACFM air flow operating condition was essentially the same as obtained with the "JM" cyclone configuration and again superior to that obtained by the "CG" cyclone configuration operating at a more favorable greater air flow operating condition.
Cyclone pressure drop characteristic was not affected by use or location of vortex breaker, resulting in an average pressure drop factor of 29.2 for cyclone inlet to outlet with spin. This value was essentially the same as was obtained with the "JM" cyclone configuration, but significantly greater than the 11.4 value obtained for the "CG" cyclone configuration.
Test results were again rational for Sedigraph particle size analyses, but inconclusive for Malvern particle size analyses.

Average "Modified JM" cyclone configuration test results were projected to CWS fuel diesel engine operating conditions in the same manner as previously described for the "CG" and "JM" cyclone configuration test results, as follows:

Cyclone diameter = 5.7 inches (see previous discussion of "JM" cyclone configuration)
Cyclone inlet velocity = 100 FPS
Cyclone pressure drop, inlet to outlet with spin = 18.0 IWG
Collection Efficiency of CWS fuel diesel engine exhaust particulate = 75.8%

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Test Series 013, performed with the "Modified JM" cyclone configuration, indicated that the cyclone pressure drop characteristic, inlet to outlet with spin, was, in accordance with theory, essentially independent of cyclone inlet velocity. The cyclone pressure drop factor was found to average 17.8 for the range of cyclone inlet velocity from 367 to 592 FPS, as compared to a factor of 18.0 determined at a cyclone inlet velocity of 579 FPS. The very slight variation of factor value indicated the factor increased as velocity increased. Therefore, the cyclone pressure drop could be slightly greater than 18.0 at the projection to the 100 FPS operating condition for CWS fuel diesel engine operation at 700 ACFM engine exhaust gas flow.

The results of Test Series 014 and 015 indicated the following:

Quantified reentrainment of collected particulate was approximately eight (8) times greater without the vortex breaker installed (Series 014), than with the vortex breaker installed.

Reentrainment increased as the level of the collected particulate in the hopper was increased. The variation was approximately 2 times greater with the vortex breaker than without.

The magnitude of the reentrainment, as measured by cyclone effluent particulate concentration, represented approximately 10% of the cyclone effluent of test cyclone particulate collection operation without the vortex breaker installed, but only approximately 1% for operation with the vortex breaker installed. This phenomenon would tend to indicate that this difference should have been detected by the Cyclone Collection Efficiency test results. As it was not detected, test results were somewhat random in regard to this test operation variable. It must be concluded that the interaction of particulate escape by failure to be collected and particulate escape by reentrainment is very complex in regard to the benefit realized by use of the vortex breaker, and, therefore, there is no clear basis for it's use.

The average test Cyclone Collection Efficiency obtained in Tests 020 and 021, performed using the "Modified JM" cyclone configuration, was 58.6%. This Collection Efficiency was clearly inferior to a typical Collection Efficiency of 65% which was obtained by previous Tests 011, 012, and 013, also performed using the "Modified JM" cyclone configuration. However, the cyclone pressure drop characteristic factor was similar to the previous test results.

Therefore, it must be concluded that the vortex breaker configuration/location investigated by Tests 020 and 021 was detrimental to Cyclone Collection Efficiency performance.

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Conclusions

The "JM" and "Modified JM" cyclone configurations exhibited an apparent superior Collection Efficiency characteristic, which was realized at the penalty of increased pressure drop, relative to the characteristics of the "CG" cyclone configuration. A normalization of the comparison was performed by projecting the "JM" and "Modified JM" test results to a reduced pressure drop equal to the "CG" cyclone pressure drop. This projection resulted in a larger cyclone size which permitted operation at a reduced cyclone inlet velocity to obtain the required cyclone pressure drop reduction. However, the reduced cyclone inlet velocity and the increased cyclone size then produced a reduction of the Cyclone Collection Efficiency. The following table illustrates the resulting comparison of cyclone Collection Efficiency performance normalized to CWS fuel diesel engine operation.

<u>Performance Parameter</u>	<u>Cyclone Configuration</u>		
	<u>"CG"</u>	<u>"JM"</u>	<u>"Modified JM"</u>
Cyclone Size/Diameter, inches	6.5	7.2	7.2
Cyclone Inlet Velocity, FPS	100	62.6	62.6
Cyclone Pressure Drop, Inlet to Outlet with Spin, IWG.	11.7	11.7	11.7
Cyclone Collection Efficiency for CWS Fuel Diesel Engine Operation, %	63.0	65.8	67.2

The table illustrates that the "JM" and "Modified JM" cyclone configurations project to a slightly superior Collection Efficiency than the "CG" cyclone. However, this slight advantage is obtained at a penalty of a larger cyclone size with a greater requirement for greater space.

A P P E N D I X 2A

DRAWING LIST

(APPENDIX 2A)

DRAWING NUMBER

S9513/MD800

S9513/MD801

DRAWING SUBJECT

NUMBER 6.5 JM-199.539 CYCLONE

NUMBER 6.5 JM-199.539S CYCLONE

NUMBER 6.5 CG-199.539 CYCLONE

PLAN

INLET FLANGE

SECTION

SECTION

1. ALL MATERIAL TO BE #16 GA. WILD STEEL UNLESS NOTED.
2. ALL WELDING TO BE COMPLETE PENETRATION MADE FROM OUTSIDE.
3. FOR THE CYCLONE CYLINDER, MAIN CONE, AND OUTLET TAIL, THE INSIDE WALL CROWN MUST BE GRINDING SMOOTH AND FLUSH WITH ADJACENT PARENT METAL, EXCEPT INSIDE 90° CORNER WELDS WHICH ARE TO BE CHIPPED TO REMOVE HOT SPOTS, ANY VOIDS IN THE WELDS ON THE INSIDE OF THE CYLINDER MUST BE FILLED PRIOR TO GRINDING SMOOTH AND FLUSH.
4. HOLES IN FLANGES TO ULTRALODE CENTRINES.
5. IF CONES ARE FORMED ON A BENDING BRAKE THEY SHOULD BE FORMED SO THAT THE INTERNAL CONTOUR SHALL BE SMOOTH AND CONTINUOUS WITH NO NOTICEABLE BENDS OR GOUGES.
6. CONES SHALL NOT BE MADE FROM MORE THAN TWO PIECES.

[illegible]

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

2

o

t

7

SECTION 2
801 SECTION 3
801 (4)- 1/2" HOLES
EQUALLY SPACED

(8)- 1/2" HOLES

SIDE ELEVATION
MODIFIED JM- DESIGN (4)- 1/2" HOLES
EQUALLY SPACED

PLATES "A", "B", AND "C" MAY BE SEPARATE PIECES.
PLATES "A" AND "B" TO BE FLAT PLATES.
PLATE "C" TO BE A SEGMENT OF A CONE
CONCENTRIC WITH CYCLONE CYLINDER.

(8)- 1/2" HOLES

DEVELOPMENT OF INLET
CLOSURE PLATE ABC

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
REVIEWED FOR ENGINEERING			
PROJECT MANAGER APPROVAL			
APPROVAL DATE			
NOT FILLED

PLAN

FRONT ELEVATION
MODIFIED JM- DESIGN

DETAIL
INLET FLANGE

SECTION.

SIDE ELEVATION
CG- DESIGN

FRONT ELEVATION
CG- DESIGN

NOTES:

1. ALL MATERIAL TO BE #16 GA. MILD STEEL UNLESS NOTED.
2. ALL WELDING TO BE COMPLETE PENETRATION MADE FROM OUTSIDE.
3. FOR THE CYCLONE CYLINDER AND OUTLET TUBE
 - a. ALL INSIDE WELD CROWNS MUST BE GROUND SMOOTH AND FLUSH WITH ADJACENT PARENT METAL, EXCEPT INSIDE 90° CORNER WELDS WHICH ARE TO BE CHIPPED TO REMOVE HIGH SPOTS, ANY VOIDS IN THE WELDS ON THE INSIDE OF THE CYCLONE MUST BE FILLED PRIOR TO GRINDING SMOOTH AND FLUSH.
4. HOLES IN FLANGES TO STRADDLE CENTERLINES.

[illegible][illegible]

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION WHITTAKER, CLARK + DANIELS - SILICA #21 LS-2160/101 DATE 12 11 84
 Density 2.5526g/cc LIQUID SEDIMENT A-12 Density .813 g/cc VISCOSITY 4.222 cp
 Preparation .6695g < 104 μ m SAMPLE DISPERSED IN 20 ml. LIQUID. TEMPERATURE 29 °C
 0.0% > 104 μ m PROGRAM STARTED AT 0.0% RATE 349 START DIA. 100 μ m

 * FIGURE 2A-1 *

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION *LS 2166 ADONEX/ALUMINUM OXIDE ACTIVATED NATURAL* DATE *7/20/90*
 Density *3.5525* g/cc LIQUID *SESSILE* D12 Density *1.508* g/cc Viscosity *4.05* cp BY *KWg*
 Preparation *0.5556g* of *100um* sample dispersed in *25 ml* *SESSILE* D12 TEMPERATURE *27* °C
25.3% *>104um* PARTICLES REMAINING IN SUSPENSION

 * FIGURE 2A-2 *

EQUIVALENT SPHERICAL DIAMETER, μm

DOE/GETS CWM DIESEL FUEL PROGRAM
 PROGRAM REF S9513/PA2
 COLD FLOW TESTS OF EMISSIONS COLLECTOR SYSTEMS
 CYCLONE ALONE COLLECTOR SYSTEM
 TEST NUMBER 000/007
 TEST DATE 04/27/90
 DATA FILE B:MASS007

CYCLONE CONFIGURATION:
 CYCLONE SERIES/DIAMETER 400/6.5
 CYCLONE INLET TYPE CG
 CYCLONE INLET AREA, SQ. FT. .117
 HOPPER VORTEX BREAKER LOCATION BOTTOM OF COLLECTION HOPPER (EFFECTIVELY REMOVED)

CYCLONE OPERATION:
 TEST AIR FLOW, ACFM 600.9052
 AIR DENSITY, LB./CU. FT. .0750076
 CYCLONE INLET VELOCITY, FPM. 5000.079
 CYCLONE INLET VP, IN. W. G. 2.165201
 CYCLONE INLET FEED, WEIGHT, GRAMS 2909.76
 CYCLONE CATCH, WEIGHT, GRAMS 2350.30
 CYCLONE INLET, SAMPLING, GRAMS 2033.456
 CYCLONE ESCAPE, SAMPLING, GRAMS 1024.270

CYCLONE PERFORMANCE:
 COLLECTION EFFICIENCY, WEIGHTS .0105067
 COLLECTION EFFICIENCY, SAMPLING .6500209
 USE COLLECTION EFFICIENCY .6500209

CYCLONE DELTA PRESSURE:
 INLET TO OUTLET, WITH SPIN, IN. W. G 24.72
 INLET TO OUTLET, WITHOUT SPIN, IN. W 26.74
 INLET TO HOPPER, IN. W. G. 13.65
 K INLET TO OUTLET, WITH SPIN 11.41696
 K INLET TO OUTLET, WITHOUT SPIN 13.27360
 P INLET TO HOPPER 9.075371

DOE/GETS CWM FUEL DIESEL
 SEDIMENT COLD FLOW CYCLONE TEST 006/007
 HALVERN COLD FLOW CYCLONE TEST 006/007
 EFFICIENCY, % LARGER CUMULATIVE (MASS)
 EFFICIENCY, % LARGER CUMULATIVE (NUMBER)
 NICKONS

INLET FEED	INLET SAMPLING	CALC. INLET
ESCAPE SAMPLING		
CALC. CATCH	CATCH	
FRAC. EFF.		

 * FIGURE 2A-3A *

CYCLONE FRACTIONAL EFFICIENCY BY SEDIGRAPH PARTICLE SIZE DISTRIBUTION (BY MASS)

51--CYCLONE INLET FEED, CYCLONE ESCAPE SAMPLING

MICRONS	MICRON RANGE	NOMINAL MICRONS	INLET % LARGER CUM.	INLET % ACTUAL	ESCAPE % LARGER CUM.	ESCAPE % ACTUAL	CALC. CATCH % ACTUAL	CALC. CATCH % ACTUAL	FRACTIONAL EFF. %	ALPHA	WEIGHT. ALPHA	BETA	WEIGHT. BETA
0	<.46	.23	100	5.5	100	10.6	1.52010	100	-10.0033	.722607	-.97403	ERROR	ERROR
.46	.46X.63	.545	94.5	6	81.4	15.0	.7422785	101.5202	0.051616	.1540235	.0241410	.1229790	.7370741
.63	.63X.86	.745	80.5	6	65.6	14.4	1.493302	100.7050	16.19094	.2372161	1.423205	.1039169	1.163501
.86	.86X1	.93	82.5	2.5	51.2	5.6	.7295431	99.29252	10.99231	.2264797	.5661992	.2236002	.5592206
1	1X1.2	1.1	80	3	45.4	6.0	.9612920	90.56297	20.05456	.2126209	.6370626	.2231436	.6694307
1.2	1.2X1.6	1.4	77	6	36.6	8.0	4.487794	97.60160	40.70024	.4700007	2.868004	.2170040	1.306024
1.6	1.6X2.2	1.9	71	5.5	29.0	10.4	2.071140	93.10309	33.97492	.2104924	1.201700	.2140564	1.177310
2.2	2.2X2.5	2.35	65.5	4.2	19.4	4	4.307300	90.23275	66.74561	.4605036	1.967715	.1923273	.0077746
2.5	2.5X2.9	2.7	61.3	2.0	15.4	3.4	2.470009	85.82545	57.60065	.3177916	.0090164	.1857561	.5401172
2.9	2.9X3.4	3.15	58.5	4.5	12	3	5.304753	83.44735	76.72193	.4627407	2.082369	.1048770	.0319467
3.4	3.4X4	3.7	54	6.5	9	2	0.914259	70.14259	89.25627	.0029320	3.919050	.1012312	1.178003
4	4X4.6	4.3	47.5	4.5	7	1.4	6.163156	89.22033	89.13690	.5162322	2.323045	.1061101	.0374955
4.6	4.6X5.4	5	43	4.5	5.6	1.4	6.163156	83.00510	89.13690	.4439597	1.997019	.1034710	.0256229
5.4	5.4X6.3	5.85	30.5	5	4.2	1	7.146000	56.90202	93.01650	.4540797	2.274090	.1767615	.0030074
6.3	6.3X7.4	6.85	33.5	0	3.2	.2	9.111712	49.75601	90.03610	.6501300	3.900700	.1735912	1.041547
7.4	7.4X8.6	8	27.5	5	3	.2	7.575210	40.64430	90.60332	.5330036	1.669410	.1744573	.0722066
8.6	8.6X10	9.3	22.5	7.3	2.0	.4	11.00106	33.00909	90.00673	.4254149	3.105523	.1734402	1.266172
10	10X12	11	15.2	6.2	1.4	.2	9.419013	22.06723	90.07304	.4070346	1.5.0574	.1859075	1.106001
12	12X14	13	9	3.5	2.2	.0	5.055056	12.64021	94.01421	.2165906	.7500951	.2006621	.7023175
14	14X16	16	5.5	3	1.6	1.6	3.751103	7.592350	81.37754	.1050501	.3151504	.2071730	.6215150
16	>10	18	2.5	2.5	0	0	3.041255	3.041255	100	ERROR	ERROR	.2049377	.5123444

TOTAL 100 100 100 6.410194 32.37064 3.010706 17.11112
 AVERAGE .3205097 .3320086 .1909390 .1074192

ALPHA & BETA--EFFICIENCY, % ***** 63.92369
 BETA & EFFICIENCY--ALPHA ***** .3493355
 ALPHA & EFFICIENCY--BETA ***** .1701662

PROJECTION TO ENGINE EXHAUST (BY MASS)

TYPICAL ENGINE EXHAUST % LARGER CUM.	TYPICAL ENGINE EXHAUST % ACTUAL	COLLECT AT TEST FRACTIONAL EFF.	BETA	WEIGHT. BETA
100	.4	.072333	ERROR	ERROR
99.6	.4	.0322065	.0007131	.0034052
99.2	1.6	.2591031	.0127495	.0203092
97.6	.6	.1139539	.0282473	.0169404
97	.5	.1042728	.0304592	.0152296
96.5	2.7	1.317203	.0296093	.0001611
93.0	0.5	2.007060	.0400033	.3460203
85.3	4.9	3.270535	.0722700	.3541269
80.4	12.2	7.027200	.0072624	1.004601
60.2	15.9	12.19079	.1319744	2.090392
52.3	10.0	9.639670	.1906394	2.050905
41.5	3.3	2.941510	.2190692	.7255603
30.2	3.5	3.119791	.2092032	.7322112
34.7	1.7	1.501202	.1900056	.3332096
33	1.7	1.680214	.1759702	.2901629
31.3	5.3	5.225976	.1569665	.0319224
26	5.5	5.354770	.1566365	.0615006
10.5	6.2	6.150166	.1504745	.9025421
14.3	5.3	4.902753	.1620759	.0590022
9	6	4.002653	.1719961	1.031977
3	3	3	.1940000	.5044263

100 75.71704 2.434023 13.29380
 .1217012 .1334719

PROJECTED TOTAL COLLECTION EFFICIENCY, % ***** 75.71704
 ALPHA & BETA--EFFICIENCY, % ***** 71.33092

S2--CYCLONE INLET SAMPLING, CYCLONE ESCAPE SAMPLING

NICROMS	NICRON RANGE	NOMINAL NICROMS	INLET % LARGER CUM.	INLET % ACTUAL	ESCAPE % LARGER CUM.	ESCAPE % ACTUAL	CALC. CATCH % ACTUAL	CALC. CATCH % LARGER CUM.	FRAC. EFF. %	ALPHA	WEIGHT. ALPHA	BETA	WEIGHT. BETA
0	<.46	.23	100	7.0	100	10.6	2.005777	100	16.73613	.7963200	6.211350	ERROR	ERROR
.46	.46X.63	.545	92.2	6.4	81.4	15.0	1.350000	97.09422	13.79039	.2724428	1.743634	.1765436	1.129079
.63	.63X.86	.745	85.0	5.0	65.6	14.4	1.106002	96.63734	13.30025	.1917007	1.111911	.2430971	1.409963
.86	.86X1	.89	80	2.0	51.2	5.0	1.190494	95.45126	27.07170	.3403305	.9753477	.2504692	.7265139
1	1X1.2	1.1	77.2	3	45.4	6.0	.9612020	94.26077	20.05456	.2126209	.6370626	.2507707	.7163122
1.2	1.2X1.6	1.4	74.2	4.0	38.6	8.0	2.053092	93.29947	35.90530	.3106125	1.529340	.2406717	1.193674
1.6	1.6X2.2	1.9	69.4	5.0	29.0	10.4	3.332090	90.64540	37.39001	.2464449	1.429301	.2283021	1.324152
2.2	2.2X2.5	2.35	63.6	3	19.4	4	2.463490	87.31330	53.44386	.3253239	.9759717	.2057076	.6171220
2.5	2.5X2.9	2.7	60.6	3	15.4	3.4	2.705309	84.04009	60.42720	.3433445	1.030033	.2003501	.6010504
2.9	2.9X3.4	3.15	57.6	3.6	12	3	3.021001	82.00450	70.90241	.3919095	1.410074	.1902233	.6046039
3.4	3.4X4	3.7	54	3.6	9	2	4.450403	78.14250	80.60161	.4432370	1.505656	.1012312	.6524324
4	4X4.6	4.3	50.4	3	7	1.4	3.050403	73.00419	83.70535	.4219300	1.265014	.1712946	.5130043
4.6	4.6X5.4	5	47.4	4	5.6	1.4	5.394005	69.02579	87.77901	.4204031	1.601612	.1622930	.6491721
5.4	5.4X6.3	5.05	43.4	4.4	4.2	1	6.224107	64.43000	92.06429	.4331270	1.905762	.1545761	.6001347
6.3	6.3X7.4	6.05	39	4	3.2	2	6.030700	58.20670	90.25414	.5909300	2.363752	.1494617	.5970467
7.4	7.4X8.6	8	35	5.4	3	2	0.100011	57.16007	90.70677	.5435030	2.934920	.1410679	.7660064
8.6	8.6X10	9.3	29.6	6.0	2.0	4	10.23361	47.97026	97.94605	.4177057	2.840942	.1415577	.9625920
10	10X12	11	22.0	7.6	2.4	2	11.570.2	33.74404	99.00113	.4263436	3.240211	.1470410	1.123591
12	12X14	13	15.2	5.6	2.2	6	0.202510	22.17453	96.25000	.2527527	1.415415	.1569096	.0791416
14	14X18	16	9.6	6	1.6	1	0.360609	13.09202	90.60077	.1403710	.0902309	.1673065	1.604317
18	>18	18	3.6	3.6	0	0	5.531400	5.531400	100	ERROR	ERROR	.1046790	.6640673

TOTAL

100

100

100

7.545476 37.19003 3.770314 16.95747

AVERAGE

.3772730 .3857007 .1005157 .1039205

ALPHA & BETA--EFFICIENCY, % ***** 67.71678
BETA & EFFICIENCY--ALPHA ***** .3420141
ALPHA & EFFICIENCY--BETA ***** .2069764

TYPICAL ENGINE EXHAUST % LARGER CUM. TYPICAL ENGINE EXHAUST % ACTUAL BETA WEIGHT. BETA COLLECT AT TEST FRAC. EFF. BETA WEIGHT. BETA

100	.4	.0069445	ERROR	ERROR
99.6	.4	.0551936	.0007131	.0034052
99.2	1.6	.2129400	.0127495	.0203992
97.6	.6	.1660302	.0202473	.0169404
97	.5	.1042720	.0304502	.0152206
96.5	2.7	.9710032	.0206093	.0001611
93.0	0.5	3.170151	.0400033	.3400203
85.3	4.9	2.610749	.0722700	.3541260
80.4	12.2	7.372120	.0072626	1.004601
60.2	15.0	11.27340	.1319744	2.090392
52.3	10.0	8.704074	.1906304	2.050905
41.5	3.5	2.762277	.2196092	.7255003
36.2	3.5	3.072205	.2092032	.7322112
34.7	1.7	1.565093	.1960056	.3332096
33	1.7	1.670320	.1759782	.2991629
31.3	5.3	5.231459	.1569665	.0319224
26	5.5	5.307033	.1566365	.0615006
20.5	6.2	6.143030	.1594745	.9025421
14.3	5.3	5.101721	.1620750	.0590022
9	6	5.441326	.1719961	1.031977
3	3	3	.1940000	.5044263

100 74.09900 2.434023 13.29300

.1217012 .1334719

PROJE TED TOTAL COLLECTION EFFICIENCY, % **** 74.09900

ALPHA & BETA--EFFICIENCY, % ***** 74.29510

* FIGURE 2A-3C *

93--CYCLONE CATCH, CYCLONE ESCAPE SAMPLING

NICROMS	NICROW RANGE	NOMINAL MICROMS	CATCH % LARGER CUN.	CATCH % ACTUAL	ESCAPE % LARGER CUN.	ESCAPE % ACTUAL	CALC. INLET % ACTUAL	CALC. INLET % LARGER CUN.	FRACTION EFF. %	ALPHA	WEIGHT. ALPHA	BETA	WEIGHT. BETA
0	.146	.23	100	1.6	100	10.6	7.535900	100	13.81819	.6465699	4.812491	ERROR	ERROR
.46	.461.63	.545	90.4	.2	81.4	15.0	5.647069	92.46409	2.305015	.0427809	.2416320	.1703257	.9610409
.63	.631.86	.745	90.2	.4	65.6	16.4	5.200395	86.01702	4.922695	.0677502	.3503324	.2243920	1.106670
.86	.861.1	.93	97.0	.0	51.2	5.0	2.545055	81.52063	20.45140	.2460237	.6263408	.2374604	.6045399
1	1.11.2	1.1	97	1	45.4	6.0	3.025192	78.98277	21.51364	.2202230	.6662169	.2159404	.7137652
1.2	1.211.6	1.4	96	2.2	38.6	8.0	4.504529	75.95750	31.70631	.2732321	1.230702	.2291626	1.032270
1.6	1.612.2	1.9	93.0	4	29.0	10.4	6.234695	71.45305	41.75530	.2844027	1.773653	.2100010	1.309791
2.4	2.412.5	2.55	89.6	1.6	19.4	4	2.508176	65.21036	45.61572	.2591094	.6656440	.1962060	.4905667
2.5	2.512.9	2.7	88	2.4	15.4	3.4	2.749171	62.65010	56.01674	.3110064	.9550090	.1070415	.5142090
2.6	2.613.4	3.15	85.6	4	12	3	3.650829	59.90101	71.30752	.3963604	1.447044	.1767162	.6451604
3.4	3.414	3.7	81.6	4.2	9	2	3.431024	56.25010	79.65009	.4303075	1.476740	.1692230	.5807463
4	4.414.6	4.3	77.4	4.6	7	1.4	3.482653	52.01036	85.00350	.4506315	1.590209	.1595770	.5557542
4.6	4.615.4	5	72.0	6.2	5.0	1.4	4.523979	49.33570	89.19440	.4450226	2.013273	.1535910	.6940459
5.4	5.416.3	5.05	66.6	7.2	4.2	1	5.035139	44.01172	93.00531	.4561760	2.296914	.1406402	.7404645
6.3	6.317.4	6.05	59.4	8.2	3.2	.2	5.406631	39.77659	98.70036	.6349201	3.432022	.1463320	.7911633
7.4	7.418.6	8	51.2	8.0	3	.2	5.797129	34.36995	90.79537	.5523742	3.202105	.1443226	.8366560
8.6	8.619	9.3	42.4	10.2	2.0	.4	6.770123	28.57203	97.03942	.4174392	2.929454	.1456644	.9073315
10	10112	11	32.2	11.0	2.4	.2	7.749615	21.79470	99.09907	.4201159	3.317733	.1527503	1.100056
12	12116	13	20.4	10.4	2.2	.6	6.978123	14.06509	96.99772	.2696760	1.001030	.1635740	1.141445
14	14118	16	10	7.0	1.6	1.6	5.035139	7.006963	90.00509	.1444507	.0139999	.1092671	1.000540
18	>18	18	2.2	2.2	0	0	1.431024	1.431024	100	ERROR	ERROR	.2359012	.3377609
TOTAL				100		100				6.902755	35.59240	3.673661	16.38059
AVERAGE										.3491379	.3612996	.1036930	.1772420

ALPHA & BETA--EFFICIENCY, % ***** 67.00042
 BETA & EFFICIENCY--ALPHA ***** .3303674
 ALPHA & BETA--EFFICIENCY, % ***** .1920300

TYPICAL ENGINE EXHAUST % LARGER CUN. TYPICAL ENGINE EXHAUST % ACTUAL BETA WEIGHT. BETA COLLECT AT TEST FRAC. EFF. BETA WEIGHT. BETA

100	.4	.0552720	ERROR	ERROR
99.6	.4	.0002201	.0007131	.0034052
99.2	1.6	.0707031	.0127495	.0203992
97.6	.6	.1227004	.0202673	.0169404
97	.5	.1075002	.0704592	.0152296
96.5	2.7	.0502304	.0296093	.0001611
93.0	8.5	3.549201	.0400033	.3400203
65.3	4.9	2.235170	.0727700	.3541269
80.4	12.2	6.931642	.0072624	1.064601
68.2	15.9	11.33790	.1319744	2.090392
52.3	10.0	0.002307	.1906394	2.050905
41.5	3.3	2.036790	.2190692	.7255603
38.2	3.5	3.121007	.2002032	.7322112
34.7	1.7	1.502110	.1900056	.3332096
33	1.7	1.670042	.1750702	.2991029
31.3	5.3	5.236154	.1569665	.0319224
26	5.5	5.306600	.1566365	.0615006
20.5	6.2	6.144130	.1504745	.9025421
14.3	5.3	5.160079	.1620759	.0590022
9	6	5.405154	.1719961	1.031977
3	3	3	.1940000	.5044263

100 73.41972 2.434023 13.29300

.1217012 .1336719

PROJECTED TOTAL COLLECTION EFFICIENCY, % **** 73.41972

ALPHA & BETA--EFFICIENCY, % ***** 73.02353

CYCLONE FRACTIONAL EFFICIENCY
BY HALVERN PARTICLE SIZE DISTRIBUTION (BY NUMBER)

CONVERT INLET NUMBER LARGER
TO MASS LARGER NEW FILE 8:NAS5007

H6--CYCLONE INLET FEED, CYCLONE ESCAPE SAMPLING

H6--CYCLONE INLET FEED, CYCLONE ESCAPE SAMPLING																			
MICRONS	MICRON RANGE	NOMINAL MICRONS	INLET % LARGER CUM. (NUM.)	INLET % ACTUAL (NUM.)	ESCAPE % LARGER CUM. (NUM.)	ESCAPE % ACTUAL (NUM.)	INLET % ACTUAL 100/TOT. (NUM D) ³	% LARGER CUM. (MASS)	ESCAPE % ACTUAL 100/TOT. (NUM D) ³	% LARGER CUM. (MASS)	CALC. CATCH % ACTUAL (MASS)	CALC. CATCH % CUM. (MASS)	FRACTIONAL EFF. (MASS)	ALPHA (MASS)	WEIGHT. ALPHA (MASS)	BETA (MASS)	WEIGHT. BETA (MASS)		
0	<.46	.23	100	.31	100	7.73	.0037710	.0000011	100	.0940500	.0002117	100	-.000112	100	-6053.74	-10.4420	-.000020	ERROR	ERROR
.46	.462-.83	.545	99.60	.17	92.27	3.30	.0275104	.0000070	100.0000	.5471400	.0012316	99.99979	-.0000649	100.0001	-5444.50	-7.30772	-.000057	2.311e-0	1.79e-13
.63	.632-1.00	.745	99.52	.34	88.60	4.00	.1405070	.0000396	99.99999	1.607054	.0037074	99.99056	-.001976	100.0000	-3246.43	-4.71205	-.000107	.0000001	5.55e-12
.86	.862-1.2	.93	99.10	.87	84.01	2.44	.0563050	.0000150	99.99995	1.062631	.0044177	99.99476	-.002346	100.0027	-9620.59	-4.92132	-.000070	.0000006	8.94e-12
1	1.21-1.6	1.4	98.9	.31	79.59	6.24	.05004	.0002307	99.99000	17.12256	.0305417	99.98201	-.020309	100.0094	-5513.37	-2.07695	-.000690	.0000012	2.06e-10
1.2	1.612-2	1.9	98.50	.40	73.15	7.91	.3.29232	.0000279	99.99002	54.25460	.1221236	99.94347	-.004094	100.0297	-4435.53	-2.01456	-.001069	.0000024	2.220e-9
1.6	2.212-2.5	2.35	98.11	.2	65.44	4.40	2.595575	.0007315	99.99000	50.14000	.1300712	99.92135	-.009009	100.0930	-6146.67	-1.75942	-.001207	.0000060	4.350e-9
2.2	2.512-2.9	2.7	97.91	.31	60.96	5.24	6.10173	.0017197	99.99796	103.1300	.2321507	99.69048	-.121911	100.1629	-4613.79	-1.42707	-.002454	.0000002	1.405e-0
2.5	2.912-3.4	3.15	97.6	.24	55.72	6.10	7.50141	.0021162	99.99624	192.5362	.4333059	99.45032	-.229264	100.2040	-7057.65	-1.35500	-.002066	.0000130	2.743e-0
3.4	3.412-4	3.7	97.38	.3	49.56	7.12	15.1959	.0042020	99.99412	360.6404	.8117072	99.02493	-.420950	100.5141	-6510.50	-1.13310	-.004053	.0000173	.0000001
4	4.412-4.6	4.3	97.00	.15	42.44	7.03	11.02605	.0033612	99.99004	550.8342	1.250123	99.21313	-.669021	100.9430	-12969.7	-1.13323	-.003000	.0000254	.0000001
4.6	4.612-5	5	96.01	.43	35.41	6.52	53.75	.0151400	99.99640	815	1.034510	96.95501	-.960942	101.6129	-4120.44	-.740004	-.011345	.0000294	.0200004
5.4	5.412-6.3	5.05	96.40	.44	20.09	5.71	80.00072	.0240260	99.97133	1143.151	2.573156	95.12050	-1.34236	102.5730	-3519.96	-.613465	-.015230	.0000531	.0000013
6.3	6.312-7.4	6.05	96.04	.65	23.10	4.6	200.9224	.0500023	99.94650	1470.520	3.320066	92.54735	-1.69504	103.9162	-1873.54	-.435300	-.025637	.0000049	.0000050
7.4	7.412-8.6	8	95.39	1.23	10.50	4.12	820.76	.1774904	99.80762	2109.44	4.740206	89.21920	-2.27471	105.6112	-834.009	-.270302	-.040573	.0001510	.0000270
8.6	8.612-10	9.3	94.16	3.07	14.46	3.57	3112.002	.0732233	99.71013	2071.554	6.463674	84.47107	-2.11977	107.0059	-157.252	-.101600	-.009136	.0003375	.0002961
10	10.12-12	11	90.29	9.03	10.09	3.21	12010.83	.3.07394	99.83201	4272.51	9.617130	70.00740	.0451272	110.0057	.0670409	.0007017	.0026017	.9011741	.0039770
12	12.12-14	13	81.26	17.7	7.00	2.33	30006.0	10.95001	95.44541	5119.01	11.52254	60.39027	10.65791	109.9600	63.29000	.0770064	.0440526	.0030046	.0425749
14	14.12-16	16	63.56	40.05	5.35	3.42	167321.6	47.15702	84.40560	14000.32	31.53170	56.06773	55.54092	99.30265	76.65200	.0009103	4.207401	.0120421	.5670757
16	>10	10	22.71	1.93	1.93	1.93	132444.7	37.32700	37.32700	11255.70	25.33595	25.33595	43.76173	43.76173	76.30040	.0799040	2.905642	.0547450	2.043556

TOTAL 100 100 354013.5 100 44426.04 100 100 -52.3546 7.911317 .0725704 2.650313

AVERAGE

-2.49300 .0791132 .0036209 .0265031

ALPHA & BETA--EFFICIENCY, % .00000000 76.04952
BETA & EFFICIENCY--ALPHA .00000000 .0495490
ALPHA & EFFICIENCY--BETA .00000000 .0424444

PROJECTION TO ENGINE EXHAUST (BY MASS)

TYPICAL ENGINE EXHAUST & LARGER CUM	TYPICAL ENGINE EXHAUST & ACTUAL	COLLECT AT TEST FRAC. EFF.	BETA (MASS)	WEIGHT. BETA (MASS)
100	.4	-27.4150	ERROR	ERROR
99.6	.4	-21.7783	.0007131	.0034852
99.2	1.0	-51.9429	.0127405	.0203802
97.6	.6	-57.7235	.0202473	.0100404
97	.5	-17.0505	.0304502	.0152286
96.5	2.7	-140.001	.0290093	.0001811
93.8	8.5	-302.120	.0400033	.3400203
85.3	4.0	-301.107	.0722700	.3541209
80.4	12.2	-502.003	.0072024	1.064001
80.2	15.9	-1122.17	.1310744	2.000302
52.3	10.0	-703.000	.1000304	2.050905
41.5	3.3	-427.000	.2100002	.7255603
38.2	3.5	-144.495	.2092032	.7322112
34.7	1.7	-50.0224	.1000056	.3332006
33	1.7	-31.0501	.1750702	.2991629
31.3	5.3	-44.2072	.1500005	.0319224
26	5.5	-0.64004	.1500305	.0015006
20.5	6.2	.0537505	.1504745	.9025421
14.3	5.3	3.354374	.1020750	.0500022
9	6	4.500160	.1719061	1.031977
3	3	2.209012	.1940000	.5044263
100	-4104.76	2.434023	13.29300	
			.1217012	.1334719

PROJECTED TOTAL COLLECTION EFFICIENCY, % 8000 -4104.76
 ALPHA & BETA--EFFICIENCY, % 80000000000000000000 37.21403

MS--CYCLONE INLET SAMPLING, CYCLONE ESCAPE SAMPLING

MS-CYCLOME INLET SAMPLING, CYCLOME ESCAPE SAMPLING																				
NICRONS	NICRON RANGE	NOMINAL NICRONS	INLET	INLET	ESCAPE	ESCAPE	INLET	I	% LARGER	ESCAPE	I	% LARGER	CALC.	CALC.	FRAC.	ALPHA	WEIGHT.	BETA	WEIGHT.	
			% LARGER	% ACTUAL	% LARGER	% ACTUAL	% ACTUAL	100/TOT.	CUM.	% ACTUAL	100/TOT.	CUM.	CATCH	CATCH	EFF.					ALPHA
			CUM.	(NUM.)	CUM.	(NUM.)	(NUMBER)	I	(MASS)	I	(MASS)	(MASS)	(MASS)	(MASS)	(MASS)	(MASS)	(MASS)	(MASS)	(MASS)	
0	<.46	.23	100	2.19	100	7.73	.0266457	.0000106	100	.0940509	.0002117	100	.000097	100	-590.707	-0.45294	.0000009	ERROR	ERROR	
.46	.46X.63	.545	97.01	.50	92.27	3.30	.0930096	.0000373	99.9999	.5671490	.0012316	99.99979	.0000603	100.0001	-1053.71	-4.40729	.000167	.0000002	0.57e-12	
.63	.63X.86	.745	97.23	.59	88.89	4.00	.2639612	.0000969	99.9995	1.607054	.0037974	99.99856	.001099	100.0007	-1269.04	-3.51235	.000340	.0000000	7.36e-11	
.86	.86X1	.93	96.64	.23	84.01	2.44	.1050021	.0000734	99.99906	1.062631	.0044177	99.99476	.002257	100.0026	-2000.25	-3.27301	.000240	.0000017	1.24e-10	
1	1X1.2	1.1	96.41	.29	82.37	2.70	.30509	.0001532	99.99970	3.70010	.0083209	99.99034	.004233	100.0040	-1197.82	-2.67672	.000410	.0000022	3.34e-10	
1.2	1.2X1.6	1.4	96.12	.79	79.59	6.24	2.10776	.0000600	99.99903	17.12250	.0305417	99.98201	.019355	100.0091	-1463.75	-1.96405	.001690	.0000031	2.63e-9	
1.6	1.6X2.2	1.9	95.33	1.09	73.35	7.91	7.47631	.0020601	99.99077	54.25469	.1221236	99.94347	.060959	100.0204	-1336.60	-1.40259	.004163	.0000077	2.205e-8	
2.2	2.2X2.5	2.35	94.24	.77	65.44	4.40	9.902904	.0039672	99.99500	50.14000	.1300712	99.92135	.064117	100.0094	-1051.05	-1.03998	.004126	.0000191	.0000001	
2.5	2.5X2.9	2.7	93.47	.94	60.96	5.24	10.50202	.0073453	99.99103	103.1399	.2321507	99.69040	.113260	100.1535	-1003.60	.000320	.006532	.0000327	.0000002	
2.9	2.9X3.4	3.15	92.53	1.02	55.72	6.16	31.00009	.0126560	99.98449	192.5302	.4333059	99.45032	.213065	100.2660	-1095.61	.787696	.000970	.0000535	.0000007	
3.4	3.4X4	3.7	91.51	1.29	49.56	7.12	65.36237	.0250410	99.97103	300.6494	.0117972	99.02493	.395673	100.4700	-992.606	.646279	.016765	.0000029	.0000021	
4	4X4.6	4.3	90.22	1.55	42.44	7.03	123.2350	.0409247	99.94509	550.9342	1.250123	90.21313	.599013	100.0755	-797.910	.510442	.024973	.0001353	.0000006	
4.6	4.6X5.4	5	88.67	2.14	35.41	6.52	267.5	.1001077	99.89000	815	1.034510	96.95501	.021045	101.4753	-503.175	.359407	.030100	.0002261	.0000230	
5.4	5.4X6.3	5.85	86.53	2.6	20.00	5.71	520.5242	.2060406	99.79077	1143.151	2.573156	95.12050	.166339	102.2964	-334.702	.251227	.051916	.0003070	.0000002	
6.3	6.3X7.4	6.85	83.93	3.50	23.10	4.6	1150.000	.4560212	99.50412	1470.520	3.320066	92.54735	.100361	103.3594	-154.301	.136301	.002265	.0006615	.0000222	
7.4	7.4X8.6	8	80.35	4.75	10.50	4.12	2432	.9655002	99.12730	2109.44	4.740206	89.21920	.100392	104.4430	-71.7160	.067505	.065253	.0011045	.0011436	
8.6	8.6X10	9.3	75.6	6.4	14.46	3.57	5147.005	2.043715	90.10179	2071.554	6.463674	84.47107	.321602	105.5069	-10.4326	.010670	.021007	.0021573	.0040090	
10	10X12	11	69.2	9.65	10.09	3.21	13110.35	5.204021	90.11006	4272.51	9.617130	70.00740	2.637600	105.6345	35.40244	.0390393	.2073566	.0035593	.0060073	
12	12X14	13	59.35	15.45	7.60	2.33	33943.65	13.47566	90.91326	5119.01	11.52254	60.39027	14.52351	102.9960	70.14366	.0923025	1.253001	.0079307	.1069792	
14	14X18	16	43.9	35.12	5.35	3.42	143051.5	57.10910	77.43760	14000.32	31.53178	56.06773	70.03151	80.47337	80.72117	.1020051	5.075607	.0102641	1.043040	
18	18	10	0.70	0.70	1.93	1.93	51204.06	20.32041	20.32041	11255.76	25.33595	25.33595	17.64106	17.64106	56.40170	.0462216	.9396116	.0005004	1.799235	
TOTAL			100			100			100			100			-30.1057			7.966779	.1236249	2.975039
AVERAGE															-1.43741			.0706670	.0061012	.0297504

ALPHA & BETA--EFFICIENCY, % ***** 72.00505
 BETA & EFFICIENCY--ALPHA ***** .0554674
 ALPHA & EFFICIENCY--BETA ***** .0427419

TYPICAL ENGINE EXHAUST % LARGER CUM	TYPICAL ENGINE EXHAUST % ACTUAL	COLLECT AT TEST FRAC. EFF.	BETA (MASS) EFF.	WEIGHT. BETA (MASS)
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100	.4	-2.30515	ERROR	ERROR
99.8	.4	-4.21405	.0007131	.0034052
99.2	1.6	-20.3047	.0127405	.0203002
97.8	.8	-12.0015	.0202473	.0180404
97	.5	-8.00012	.0304502	.0152200
96.5	2.7	-30.5212	.0200093	.0001011
93.8	8.5	-113.610	.0400033	.3400203
85.3	4.8	-51.5407	.0722700	.3541260
80.4	12.2	-122.430	.0072626	1.004001
68.2	15.8	-174.202	.1319744	2.090302
52.3	10.8	-107.211	.1000304	2.050005
41.5	7.3	-26.3310	.2100002	.7255003
38.2	3.5	-17.6111	.2002032	.7322112
34.7	1.7	-5.00130	.1900050	.3332000
33	1.7	-2.02447	.1750702	.2001020
31.3	5.3	-3.00000	.1500005	.0310224
28	5.5	-.573705	.1560305	.0015000
20.5	6.2	2.100011	.1504745	.0025421
14.3	5.3	3.717014	.1020750	.0500022
9	6	4.043270	.1719901	1.031077
3	3	1.604451	.1940000	.5044203

100 -700.015 2.434023 13.20300

.1217012 .1336710

PROJECTED TOTAL COLLECTION EFFICIENCY, % 0000 -700.015

ALPHA & BETA--EFFICIENCY, % 0000000000000000 37.37021

* FIGURE 2A-3H *

NO--CYCLONE CATCH, CYCLONE ESCAPE SAMPLING

CATCH																			
WICRONS	WICRON RANGE	NOMINAL WICRONS	CATCH % LARGER CUM. (NUM.)	CATCH % ACTUAL (NUM.)	ESCAPE % LARGER CUM. (NUM.)	ESCAPE % ACTUAL (NUM.)	CATCH X % ACTUAL (NUMBER) (HON D) ³	X % ACTUAL (HON D) ³	% LARGER CUM. (MASS)	% ACTUAL (NUMBER) (HON D) ³	X % ACTUAL (HON D) ³	% LARGER CUM. (MASS)	CALC. INLET % ACTUAL (MASS)	CALC. INLET % CUM. (MASS)	FRAC. EFF. % (MASS)	ALPHA (MASS)	WEIGHT. ALPHA (MASS)	BETA (MASS)	WEIGHT. BETA (MASS)
0	<.46	.23	100	.12	100	7.73	.0016600	.0000000	100	.0040509	.0002117	100	.0000745	100	.7656614	.0336177	.0000025	ERROR	ERROR
.46	.46X.83	.545	99.00	.04	92.27	3.30	.0004751	.0000030	100.0000	.5471400	.0012316	99.99979	.0004326	99.99993	.5047400	.0107600	.0000047	.0000010	7.00e-10
.63	.63X.00	.745	99.04	.12	88.09	4.00	.0408192	.0000200	100.0000	1.007054	.0037974	99.99956	.0013453	99.99949	1.440750	.0194707	.0000262	.0000000	1.003e-9
.80	.80X1	.93	99.72	.03	84.81	2.44	.0261307	.0000145	99.99997	1.902631	.0046177	99.99470	.0015520	99.99015	.0073773	.0005509	.0000102	.0000215	3.343e-8
1	1X1.2	1.1	99.69	.03	82.37	2.70	.03003	.0000240	99.99995	3.70010	.0003209	99.99034	.0020230	99.99660	.5334001	.0040629	.0000142	.0000340	.0000001
1.2	1.2X1.6	1.4	99.66	.00	78.59	6.24	.21952	.0001310	99.99993	17.12250	.0905417	99.98201	.0135434	99.99367	.6331693	.0045370	.0000614	.0000527	.0000007
1.6	1.6X2.2	1.9	99.50	.11	73.35	7.91	.75449	.0004520	99.99980	54.25489	.1221230	99.94347	.0429360	99.98013	.6064324	.0036253	.0001557	.0001262	.0000053
2.2	2.2X2.5	2.35	99.47	.06	65.44	4.40	.7706725	.0004674	99.99934	50.14000	.1300712	99.92135	.0400006	99.97719	.6011409	.0020232	.0001299	.0002050	.0000131
2.5	2.5X2.9	2.7	99.41	.00	60.86	5.24	1.57464	.0000451	99.99000	103.1300	.2321507	99.69040	.0016702	99.89110	.7530931	.0027990	.0002267	.0004355	.0000356
2.9	2.9X3.4	3.15	99.33	.12	55.72	6.16	6.251175	.0037520	99.90793	192.5362	.4333059	99.45032	.1537670	99.80951	1.500071	.0050020	.0007014	.0000575	.0001011
3.4	3.4X4	3.7	99.13	.37	49.56	7.12	10.74101	.0112400	99.69410	300.0494	.8117972	99.02693	.2907773	99.65575	2.517793	.0060920	.0020040	.0010143	.0002949
4	4X4.6	4.3	98.76	.87	42.44	7.03	77.12170	.0462097	99.90293	550.9342	1.250123	90.21313	.4694260	99.36407	6.417751	.0154255	.0072411	.0015926	.0007476
4.6	4.6X5.4	5	97.70	2.32	35.41	6.52	290	.1740023	99.93604	015	1.034510	90.95501	.7530425	90.89554	15.02765	.0325609	.0245510	.0024144	.0010200
5.4	5.4X6.3	5.05	95.47	5.27	20.09	5.71	1055.063	.6332043	99.76250	1143.151	2.573156	95.12050	1.310610	90.14170	31.44674	.0045400	.0045074	.0034737	.0045527
6.3	6.3X7.4	6.05	90.2	8.0	23.10	4.6	3102.040	1.000914	90.12931	1470.520	3.320066	92.54735	2.405001	90.03100	51.60315	.1061003	.2553026	.0051115	.0122035
7.4	7.4X8.6	8	80.3	14.05	10.50	4.12	7003.2	4.503554	87.21940	2100.44	4.740200	89.21020	4.620020	84.42509	64.17610	.1203107	.5930073	.0077505	.0350606
8.6	8.6X10	8.3	65.45	17.16	14.46	3.57	13002.77	0.204020	92.05504	2071.554	6.463074	84.47107	7.640003	89.79796	70.49305	.1312413	1.003039	.0125120	.0957000
10	10X12	11	40.29	15.92	10.00	3.21	21109.52	12.71027	84.37122	4272.51	9.617130	70.00740	11.63544	82.34016	71.13060	.1120730	1.314490	.0106634	.2207910
12	12X14	13	32.37	12.00	7.60	2.33	27014.02	10.69430	71.05205	5119.01	11.52254	60.39027	14.00053	70.51372	72.97692	.1000522	1.490504	.0291136	.4334504
14	14X16	16	19.71	13.47	5.35	3.42	55173.12	33.11573	54.05056	14000.32	31.53170	56.06773	32.56266	55.02519	66.10031	.0677727	2.200000	.0410953	1.304222
16	>16	18	6.24	6.24	1.93	1.03	36391.00	21.04203	21.04203	11255.76	25.33595	25.33595	23.00253	23.00253	61.04000	.0532321	1.227007	.0014970	1.378540
TOTAL				100		100	166607.0			44426.04	100		100		.9137449	8.220400	.2076003	4.057650	
AVERAGE															.0435117	.0022040	.0103030	.0405746	

ALPHA & BETA--EFFICIENCY, % 00.05324
 BETA & EFFICIENCY--ALPHA 00.0750201
 ALPHA & EFFICIENCY--BETA 00.041030

TYPICAL ENGINE EXHAUST & LARGER CON	TYPICAL ENGINE EXHAUST & ACTUAL	COLLECT AT TEST FRAC. EFF.	BETA (MASS)	WEIGHT. BETA (MASS)
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100	.4	.0030626	ERROR	ERROR
99.6	.4	.0023390	.0007131	.0034052
99.2	1.6	.0230521	.0127405	.0203002
97.6	.6	.0930443	.0202473	.0109404
97	.5	.0026675	.0304502	.0152206
96.5	2.7	.0170956	.0206093	.0001611
93.8	0.5	.0503460	.0400033	.3400203
85.3	4.9	.0324012	.0722700	.3541200
80.4	12.2	.0910774	.0072026	1.004001
68.2	15.9	.2525036	.1310744	2.000302
52.3	10.8	.2719217	.1906394	2.050005
41.5	3.3	.2117050	.2100602	.7255003
30.2	3.5	.5259077	.2002032	.7322112
34.7	1.7	.5345040	.1000056	.3332000
33	1.7	.0706135	.1759702	.2001020
31.3	5.3	3.401330	.1500005	.0319224
20	5.5	3.077110	.1506305	.0015000
20.6	0.2	4.410001	.1504745	.0025421
10.3	5.3	3.007777	.1920750	.0500022
8	6	3.071209	.1710001	1.031077
3	3	1.040227	.1940000	.5044263

100 24.20729 2.034023 13.29300

.1217012 .1334710

PROJECTED TOTAL COLLECTION EFFICIENCY, % **** 24.20729

ALPHA & BETA--EFFICIENCY, % ***** 30.11403

* FIGURE 2A-3J *

DOE/GETS CWM FUEL DIESEL

SEDIGRAPH COLD FLOW CYCLONE TEST 006/007

DOE/GETS CWM FUEL DIESEL

SEDIGRAPH COLD FLOW CYCLONE TEST 006/007

DOE/GETS CWM FUEL DIESEL

SEDIGRAPH COLD FLOW CYCLONE TEST 006/007

* FIGURE 2A-6 *

DOE/GETS CWM FUEL DIESEL

MALVERN COLD FLOW TEST 006/007

* FIGURE 2A-7A *

DOE/GETS CWM FUEL DIESEL

MALVERN COLD FLOW TEST 006/007

DOE/GETS CWM FUEL DIESEL MALVERN COLD FLOW CYCLONE TEST 006/007

- INLET SAMPLE MASS
- ×— ESCAPE SAMPLE MASS
- ▽— CALC. CATCH MASS
- #— FRAC. EFF. MASS

DOE/GETS CWM FUEL DIESEL
MALVERN COLD FLOW CYCLONE TEST 006/007

DOE/GETS CWM FUEL DIESEL

MALVERN COLD FLOW TEST 006/007

 * FIGURE 2A-9 *

DOE/GETS CWM FUEL DIESEL

COLD FLOW CYCLONE TEST 006/007

GDE/MEYS CHN FUEL DIESEL PROJECT
 GDESI LABORATORY COLD FLOW TESTS OF COLLECTOR CONCEPTS
 CYCLONE ALONE EQUIPMENT
 GDESI PROJECT REFERENCE: 00013/PA2
 FILE 0:CPCV8888
 LAST UPDATED/REVISED DATE 00/10/00

TEST SERIES NUMBER

TEST NUMBER

TEST DATE

UPDATED/REVISED DATE

CYCLONE CONFIGURATION:

STAGES
 DIAMETER, IN.
 INLET CONFIGURATION
 INLET AREA, SQ. FT.
 VENTUR ORIFICE LOCATION

TEST PARTICULATE:

MATERIAL
 MATERIAL ID#, MICROMS
 "PRODUCED" USED
 "PRODUCED" ID#, MICROMS

TEST OPERATING CONDITIONS:

AIR FLOW, ACFM
 AIR TEMPERATURE, F.
 AIR DENSITY, LB./CU. FT.
 CYCLONE INLET VELOCITY, FPM.
 CYCLONE INLET WP, IN.W.G.
 DELTA P, IN. TO OUT., WITH SPIN, IN.W.G.
 DELTA P, IN. TO OUT., NO SPIN, IN.W.G.
 DELTA P, IN. TO HSP., IN.W.G.
 K, IN. TO OUT., WITH SPIN
 K, IN. TO OUT., NO SPIN
 K, IN. TO HSP.

PROJECT TO ENGINE GAS FLOW OPERATION:

GAS FLOW, ACFM
 GAS TEMPERATURE, F.
 GAS DENSITY, LB./CU. FT.
 CYCLONE INLET VELOCITY, FPM.
 CYCLONE INLET WP, IN.W.G.
 DELTA P, IN. TO OUT., WITH SPIN, IN.W.G.
 DELTA P, IN. TO OUT., NO SPIN, IN.W.G.
 DELTA P, IN. TO HSP., IN.W.G.

FEED AND CATCH WEIGHT DATA:

CYCLONE INLET PARTICULATE CONCENTRATION, GRAINS/ACF.
 COLLECTION EFFICIENCY, % CE.W

INLET AND ESCAPE ISOKINETIC SAMPLING DATA:

CYCLONE INLET PARTICULATE CONCENTRATION, GRAINS/ACF.
 COLLECTION EFFICIENCY, % CE.S

FRACTIONAL EFFICIENCY BY SEDIMENT ANALYSIS/MMSD, USING CE.S:

INLET (FEED) AND ESCAPE (SAMPLING):
 I.F. MMSD, MICROMS
 F.S. MMSD, MICROMS
 CALC C.F. MMSD, MICROMS
 ALPHA.W

001	002	003	004	005	006	007
002	003	004	005	006	007	008
4/12/00	4/18/00	4/19/00	4/24/00	4/24/00	4/28/00	4/28/00
04/19/00	04/19/00	04/19/00	04/19/00	04/19/00	04/19/00	04/19/00
200	200	200	200	200	200	200
0.5	0.5	0.5	0.5	0.5	0.5	0.5
CO	CO	CO	CO	CO	CO	CO
.117	.117	.117	.117	.117	.117	.117
TOP 020.007	020.000	020.000	TOP 020.007	020.007	020.007	TOP 020.007
011004	011004	011004	011004	011004	011004	011004
3.0	3.0	3.0	3.0	3.0	3.0	3.0
NONE	NONE	NONE	NONE	NONE	NONE	NONE
NONE	NONE	NONE	NONE	NONE	NONE	NONE
000	005	000	000	004	000	000
00	100	00	107	114	100	102
.077	.070	.0702	.0701	.0600	.0701	.0707
00.00010	07.17000	04.07170	02.10020	01.02000	00.14010	00.00070
2.100	2.100	2.11	.011	.7000	2.100	2.10
24.04	25.05	25.02	0.00	0.00	24.72	25.10
20.20	30	20.00	10.15	10.00	20.74	20.04
10.00	10.02	10.20	5.00	5	10.00	17.20
11.00	11.04	12.14	10.07	10.00	11.02	11.04
10.04	10.00	10.00	12.02	12.70	10.27	10.00
0.40	7.21	0.70	0.10	0.04	0.00	7.02
700	700	700	700	700	700	700
700	700	700	700	700	700	700
.0040072	.0040072	.0040072	.0040072	.0040072	.0040072	.0040072
00.71010	00.71010	00.71010	00.71010	00.71010	00.71010	00.71010
1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
11.70200	12.07010	12.00000	10.00000	11.07000	11.00000	11.77010
10.01000	14.10000	14.27000	12.77000	10.01700	10.00000	10.70100
0.021112	7.35000	0.00000	0.01000	0.00000	0.00000	0.00000
1.10	0.07	1.11	0.02	.02	1.00	1.07
51.77	51.77	57.07	40.00	30.00	01.00	04.00
1.04	0.00	1.01	0.04	0.07	1.00	0.00
03.77	01.00	00.00	51.00	40.00	00.00	01.04
3.0	3.0	3.0	3.0	3.0	3.0	3.0
0.0	0.0	0.7	0.0	0.0	0.0	0.7
0.1	0.0	0.2	0.0	7.4	0.1	0.3
0.3044	0.1219	0.1900	0.0900	0.0901	0.3321	0.2415

BETA,M	0.1074	0.1074	0.1074	0.1074	0.1074	0.1074	0.1074
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M	00.04	40.19	51.07	54.53	52.40	00.02	50.50
PROJECTION TO ENGINE PARTICULATE:							
I,P,ENGINE IND, MECHAN (BODOGRAPH/MAG)	3.5	3.5	3.5	3.5	3.5	3.5	3.5
BETA,M,ENGINE	0.1205	0.1205	0.1205	0.1205	0.1205	0.1205	0.1205
COLLECTION EFFICIENCY, S, TEST PRAC. EFF. AND I,P,ENG.	70.40	01.21	70.13	00.20	05.00	70.72	70.20
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M,ENGINE	73.10	40.55	50.70	42.54	40.20	71.03	04.00
PROJECTION TO ENGINE OPERATION:							
CYCLONE DIAMETER, INCHES	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ALPHA, ENGINE	0.2227	0.0700	0.1227	0.0021	0.0700	0.2010	0.1404
COLLECTION EFFICIENCY, S, ALPHA, ENGINE & BETA, ENGINE	00.50	50.47	47.00	50.00	50.00	00.12	02.31
COLLECTION EFFICIENCY, S, P.E., ENGINE & I, P, ENGINE	00.54	01.00	00.45	01.04	50.07	00.01	01.07

INLET (SAMPLING) AND ESCAPE (SAMPLING):

I,S IND, MECHAN	3.0	2.0	3.0	NA	NA	4.0	NA
E,S IND, MECHAN	0.3	0.0	0.7	0.0	0.0	0.0	0.7
CALC. C,S IND, MECHAN	0.0	0.4	0.2	NA	NA	7.0	NA
ALPHA,M	0.0007	0.0000	0.3427	NA	NA	0.0000	NA
BETA,M	0.1005	0.2002	0.2010	NA	NA	0.1000	NA
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M	07.01	00.13	50.04	NA	NA	07.72	NA
PROJECTION TO ENGINE PARTICULATE:							
I,P,ENGINE IND, MECHAN (BODOGRAPH/MAG)	3.5	3.5	3.5	3.5	3.5	3.5	3.5
BETA,M,ENGINE	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
COLLECTION EFFICIENCY, S, TEST PRAC. EFF. AND I,P,ENG.	70.00	01.00	70.70	NA	NA	74.10	NA
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M,ENGINE	70.31	72.75	71.07	NA	NA	74.00	NA
PROJECTION TO ENGINE OPERATION:							
CYCLONE DIAMETER, INCHES	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ALPHA, ENGINE	0.2241	0.2100	0.2124	NA	NA	0.2307	NA
COLLECTION EFFICIENCY, S, ALPHA, ENGINE & BETA, ENGINE	02.07	01.00	01.41	NA	NA	00.00	NA
COLLECTION EFFICIENCY, S, P.E., ENGINE & I, P, ENGINE	04.07	00.50	02.04	NA	NA	00.40	NA

CATCH AND ESCAPE (SAMPLING):

C IND, MECHAN	7.0	7.0	7.2	0.5	0.0	7.5	7.7
E,S IND, MECHAN	0.0	0.0	0.7	0.0	0.0	0.0	0.7
CALC. I IND, MECHAN	3.0	3.2	3.3	3.2	2.0	4.0	4.2
ALPHA,M	0.3101	0.0000	0.2000	0.2000	0.2140	0.3010	0.0000
BETA,M	0.1740	0.2200	0.2001	0.2124	0.2007	0.1772	0.1000
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M	04.21	00.15	00.54	40.00	47.00	07.00	00.10
PROJECTION TO ENGINE PARTICULATE:							
I,P,ENGINE IND, MECHAN (BODOGRAPH/MAG)	3.5	3.5	3.5	3.5	3.5	3.5	3.5
BETA,M,ENGINE	0.1200	0.1200	0.1200	0.1200	0.1200	0.1200	0.1200
COLLECTION EFFICIENCY, S, TEST PRAC. EFF. AND I,P,ENG.	70.00	70.00	70.00	04.00	00.00	70.42	70.41
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M,ENGINE	70.11	71.01	74.10	00.04	01.07	70.02	07.77
PROJECTION TO ENGINE OPERATION:							
CYCLONE DIAMETER, INCHES	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ALPHA, ENGINE	0.1014	0.2040	0.2070	0.1000	0.1700	0.2100	0.1701
COLLECTION EFFICIENCY, S, ALPHA, ENGINE & BETA, ENGINE	50.01	00.54	04.05	55.51	57.00	02.12	50.00
COLLECTION EFFICIENCY, S, P.E., ENGINE & I, P, ENGINE	04.35	00.05	00.04	00.01	00.01	02.40	00.70

FRACTIONAL EFFICIENCY BY ANALYSIS ANALYSED/MAG, USING CE,S:

INLET (FEED) AND ESCAPE (SAMPLING):							
I,P IND, MECHAN	10.0	NA	10.0	10.0	10.0	10.0	10.0
E,S IND, MECHAN	15.0	NA	10.1	17.5	10.1	14.0	14.5
CALC. C,P IND, MECHAN	17.4	NA	10.5	10.0	10.4	17.5	17.0
ALPHA,M	0.0719	NA	0.0099	0.0500	0.0013	0.0751	0.0734
BETA,M	0.0740	NA	0.0200	0.0200	0.0200	0.0200	0.0200
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M	73.54	NA	72.45	00.50	00.70	70.05	73.42

PROJECTION TO ENGINE PARTICULATE:						
I.P.ENGINE IND. NOISE (DECEMBER/1988)	3.5	NA	3.5	3.5	3.5	3.5
BETA.W.ENGINE	0.1335	NA	0.1335	0.1335	0.1335	0.1335
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.P.ENG.	-2000	NA	-1700	-9500	-3201	-4100
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W.ENGINE	35.03	NA	34.37	30.30	31.00	37.21
INLET (DAMPING) AND ESCAPE (DAMPING):						
I.S IND. NOISE	19.4	NA	19.1	19.0	14.7	19.0
E.S IND. NOISE	15	NA	19.1	17.5	10.1	14.0
CALC. C.S IND. NOISE	19.0	NA	19.7	19.0	13.0	14.4
ALPHA.W	0.0730	NA	0.0000	0.0700	0.0000	0.0707
BETA.W	0.0340	NA	0.0000	0.0000	0.0000	0.0000
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W	07.07	NA	74.04	90.00	72.05	72.61
PROJECTION TO ENGINE PARTICULATE:						
I.P.ENGINE IND. NOISE (DECEMBER/1988)	3.5	NA	3.5	3.5	3.5	3.5
BETA.W.ENGINE	0.1335	NA	0.1335	0.1335	0.1335	0.1335
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.P.ENG.	-1120	NA	-100	-174	-371	-701
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W.ENGINE	35.00	NA	34.00	30.00	41.01	37.00
ENTER AND ESCAPE (DAMPING):						
C IND. NOISE	19.9	NA	17.0	16.4	10.2	14.6
E.S IND. NOISE	15.0	NA	19.1	17.5	10.1	14.0
CALC. I IND. NOISE	19.1	NA	17.4	19.0	10.0	14.0
ALPHA.W	0.0004	NA	0.0004	0.0004	0.0004	0.0002
BETA.W	0.0025	NA	0.0000	0.0700	0.0004	0.0000
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W	07.70	NA	00.30	02.00	02.37	00.00
PROJECTION TO ENGINE PARTICULATE:						
I.P.ENGINE IND. NOISE (DECEMBER/1988)	3.5	NA	3.5	3.5	3.5	3.5
BETA.W.ENGINE	0.1335	NA	0.1335	0.1335	0.1335	0.1335
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.P.ENG.	17.02	NA	24.14	17.21	10.43	24.20
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W.ENGINE	33.00	NA	32.05	27.42	27.42	30.11

DOE/NETS GAS FUEL DIESEL PROJECT
 GASES LABORATORY GILD FLOW TESTS OF COLLECTOR CONCEPTS
 CYCLONE ALONE EQUIPMENT
 GASES PROJECT REFERENCE: G0018/PAR
 FILE 8-CFV0000
 LAST UPDATED/REVISED DATE 08/19/90

TEST SERIES NUMBER	000	000	010	011	012	010	010	010	010
TEST NUMBER	000	010	011	012	013	-A-	-B-	-C-	-D-
TEST DATE	1/4/90	5/11/90	05/15/90	05/15/90	05/24/90	05/25/90	05/25/90	05/25/90	05/25/90
UPDATED/REVISED DATE	08/19/90	08/19/90	08/19/90	08/19/90	08/19/90	08/25/90	08/25/90	08/25/90	08/25/90
CYCLONE CONFIGURATION:									
SERIES	200	200	200	200	200	200	200	200	200
DIAMETER, IN.	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
INLET CONFIGURATION	JN	JN	JN	JN	JN	JN	JN	JN	JN
INLET AREA, SQ. FT.	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904
VERTICAL ORIGIN LOCATION	OUT. COL. TOP 002.	OUT. COL. TOP 002.	OUT. COL. TOP 002.007.	OUT. COL. TOP 002.007.	OUT. COL. TOP 002.007.	OUT. COL. TOP 002.007.	OUT. COL. TOP 002.007.	OUT. COL. TOP 002.007.	OUT. COL. TOP 002.007.
TEST PARTICULATE:									
MATERIAL	0110CA	0110CA	0110CA	0110CA	0110CA	NA	NA	NA	NA
MATERIAL WGT, MCG/SEC	3.0	3.0	3.0	3.0	3.0	NA	NA	NA	NA
"PRECIPIT" USED	NONE	NONE	NONE	NONE	NONE	NA	NA	NA	NA
"PRECIPIT" WGT, MCG/SEC	NONE	NONE	NONE	NONE	NONE	NA	NA	NA	NA
TEST OPERATING CONDITIONS:									
AIR FLOW, ACFM	500	501	502	571	570	507	400	500	500
AIR TEMPERATURE, F.	60	60	102	107	104	62	100	101	100
AIR DENSITY, LB./CU. FT.	.0703	.0701	.070	.070	.0703	.0721	.0702	.0704	.0704
CYCLONE INLET VELOCITY, FPM.	01.04702	02.10751	02.27007	03.27071	03.10400	00.00000	04.00404	00.00000	00.00750
CYCLONE INLET UP, IN.W.G.	.0767	.0700	.0040	.0000	.0007	.000	.0711	.0400	.0000
DELTA P, IN. TO OUT., WITH SPIN, IN.W.G.	24.73	20.40	20.13	20.40	20.7	0.75	10.40	24.00	20.01
DELTA P, IN. TO OUT., NO SPIN, IN.W.G.	20.00	20.47	20.10	20.47	20.20	11.00	22.00	20.41	20.00
DELTA P, IN. TO HOP., IN.W.G.	24.2	10.00	23.0	10.00	10.24	0.40	12.02	10.00	10.44
H, IN. TO OUT., WITH SPIN	20.21	20.12	20.42	20.47	20.07	27.20	20	20.01	20.72
H, IN. TO OUT., NO SPIN	23.10	24.00	22.00	20.01	20.77	01.01	20.01	20.0	20.01
H, IN. TO HOP.	27.0	21.20	20.00	20.0	20.27	17.00	10.00	10.11	10.71
PROJECT TO ENGINE AND FLOW OPERATION:									
AIR FLOW, ACFM	700	700	700	700	700	700	700	700	700
AIR TEMPERATURE, F.	700	700	700	700	700	700	700	700	700
AIR DENSITY, LB./CU. FT.	.0042072	.0042072	.0042072	.0042072	.0042072	.0042072	.0042072	.0042072	.0042072
CYCLONE INLET VELOCITY, FPM.	77.57002	77.57002	77.57002	77.57002	77.57002	77.57002	77.57002	77.57002	77.57002
CYCLONE INLET UP, IN.W.G.	.0173000	.0173000	.0173000	.0173000	.0173000	.0173000	.0173000	.0173000	.0173000
DELTA P, IN. TO OUT., WITH SPIN, IN.W.G.	17.41002	10.90000	17.54000	10.10400	10.31007	10.01100	17.00400	10.20400	10.54000
DELTA P, IN. TO OUT., NO SPIN, IN.W.G.	20.40001	21.30270	20.54000	20.00000	20.04000	10.00000	20.00000	20.00000	20.00000
DELTA P, IN. TO HOP., IN.W.G.	17.04007	10.12070	10.47024	12.04170	12.31407	11.10001	11.00007	11.70000	12.10000
FEED AND CATCH WEIGHT DATA:									
CYCLONE INLET PARTICULATE CONCENTRATION, GRAMS/SEC.	1.02	1.01	1.00	1.00	1.00	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. CE, %	47.07	54.07	00.30	57.50	57.30	NA	NA	NA	NA
INLET AND ESCAPE ISOMETRIC SAMPLING DATA:									
CYCLONE INLET PARTICULATE CONCENTRATION, GRAMS/SEC.	0.70	0.00	0.02	0.02	1.01	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. CE, %	04.20	03.07	00.14	04.70	04.21	NA	NA	NA	NA
PARTICULATE RETENTION FROM COLLECTION HOPPER:									
HOPPER .75 FULL:									
L. C. E. . SAMPLING, GRAMS/CU. FT.	NA	NA	NA	NA	NA	NA	NA	NA	NA
WGT, C. E. . HAWKINS, MCG/SEC	NA	NA	NA	NA	NA	NA	NA	NA	NA
HOPPER .50 FULL:									
L. C. E. . SAMPLING, GRAMS/CU. FT.	NA	NA	NA	NA	NA	NA	NA	NA	NA
WGT, C. E. . HAWKINS, MCG/SEC	NA	NA	NA	NA	NA	NA	NA	NA	NA
HOPPER .75 FULL:									

L. C.E., SAMPLING, GRAINS/CU.FT.
 MOD, C.E., HALVERN, MICRONS

NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

FRACTIONAL EFFICIENCY BY SEDIMENT ANALYSIS/MOD, USING CE.0:

INLET (PESD) AND ESCAPE (SAMPLING):

I.F. MOD, MICRONS	3.0	3.0	3.0	3.0	3.0	NA	NA	NA	NA
E.S. MOD, MICRONS	0.0	0.0	0.0	0.7	0.7	NA	NA	NA	NA
CALC. C.P. MOD, MICRONS	0.1	0.2	0.1	0.1	0.0	NA	NA	NA	NA
ALPHA, M	0.0244	0.3773	0.3100	0.2700	0.0000	NA	NA	NA	NA
BETA, M	0.1074	0.1074	0.1074	0.1074	0.1074	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, M AND BETA, M	00.37	00.03	02.00	50.02	00.03	NA	NA	NA	NA

PROJECTION TO ENGINE PARTICULATE:

I.F. ENGINE MOD, MICRONS (SEDIMENT/MOD)	3.0	3.0	3.0	3.0	3.0	NA	NA	NA	NA
BETA, M, ENGINE	0.1335	0.1335	0.1335	0.1335	0.1335	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.F. ENG.	70.40	70.34	00.07	70.24	00.07	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, M AND BETA, M, ENGINE	70.00	73.00	70.30	00.03	73.10	NA	NA	NA	NA

PROJECTION TO ENGINE OPERATION:

CYCLONE DIAMETER, INCHES	5.7	5.7	5.7	5.7	5.7	NA	NA	NA	NA
ALPHA, ENGINE	0.0377	0.3175	0.2070	0.2232	0.3000	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, ENGINE & BETA, ENGINE	72.02	70.40	00.72	02.00	00.41	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. P.E., ENGINE & I. F., ENGINE	73.00	72.70	70.03	73.27	73.04	NA	NA	NA	NA

INLET (SAMPLING) AND ESCAPE (SAMPLING):

I.S. MOD, MICRONS	NA	NA	NA	NA	NA	NA	NA	NA	NA
E.S. MOD, MICRONS	0.0	0.0	0.0	0.7	0.7	NA	NA	NA	NA
CALC. C.S. MOD, MICRONS	NA	NA	NA	NA	NA	NA	NA	NA	NA
ALPHA, M	NA	NA	NA	NA	NA	NA	NA	NA	NA
BETA, M	NA	NA	NA	NA	NA	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, M AND BETA, M	NA	NA	NA	NA	NA	NA	NA	NA	NA

PROJECTION TO ENGINE PARTICULATE:

I.F. ENGINE MOD, MICRONS (SEDIMENT/MOD)	3.0	3.0	3.0	3.0	3.0	NA	NA	NA	NA
BETA, M, ENGINE	0.1335	0.1335	0.1335	0.1335	0.1335	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.F. ENG.	NA	NA	NA	NA	NA	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, M AND BETA, M, ENGINE	NA	NA	NA	NA	NA	NA	NA	NA	NA

PROJECTION TO ENGINE OPERATION:

CYCLONE DIAMETER, INCHES	5.7	5.7	5.7	5.7	5.7	NA	NA	NA	NA
ALPHA, ENGINE	NA	NA	NA	NA	NA	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, ENGINE & BETA, ENGINE	NA	NA	NA	NA	NA	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. P.E., ENGINE & I. F., ENGINE	NA	NA	NA	NA	NA	NA	NA	NA	NA

CATCH AND ESCAPE (SAMPLING):

C MOD, MICRONS	7.0	7.0	0.0	0.0	0.0	NA	NA	NA	NA
E.S. MOD, MICRONS	0.0	0.0	0.0	0.7	0.7	NA	NA	NA	NA
CALC. I MOD, MICRONS	3.7	3.0	3.7	3.7	3.4	NA	NA	NA	NA
ALPHA, M	0.3300	0.3040	0.3700	0.3304	0.3022	NA	NA	NA	NA
BETA, M	0.1020	0.1073	0.1005	0.1074	0.1002	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, M AND BETA, M	00.42	00.00	05.20	02.01	04.00	NA	NA	NA	NA

PROJECTION TO ENGINE PARTICULATE:

I.F. ENGINE MOD, MICRONS (SEDIMENT/MOD)	3.0	3.0	3.0	3.0	3.0	NA	NA	NA	NA
BETA, M, ENGINE	0.1335	0.1335	0.1335	0.1335	0.1335	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.F. ENG.	70.37	70.10	00.40	70.33	00.01	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, M AND BETA, M, ENGINE	72.95	73.72	73.70	71.41	73.07	NA	NA	NA	NA

PROJECTION TO ENGINE OPERATION:

CYCLONE DIAMETER, INCHES	5.7	5.7	5.7	5.7	5.7	NA	NA	NA	NA
ALPHA, ENGINE	0.3013	0.3009	0.3134	0.2700	0.3011	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA, ENGINE & BETA, ENGINE	69.44	69.69	70.20	67.47	69.29	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. P.E., ENGINE & I. F., ENGINE	75.74	77.57	76.04	76.10	76.03	NA	NA	NA	NA

FRACTIONAL EFFICIENCY BY HALVERN ANALYSIS/MASO, USING CE.9:

INLET (FEED) AND ESCAPE (DAMPLING):									
I.F. IND. MCGRND	10.0	10.0	10.0	10.0	10.0	NA	NA	NA	NA
E.S. IND. MCGRND	10.7	10.2	10.0	10.0	10.0	NA	NA	NA	NA
CALC. C.F. IND. MCGRND	17.0	17.5	17.5	17.5	17.4	NA	NA	NA	NA
ALPHA,M	0.0755	0.0720	0.0707	0.0772	0.0000	NA	NA	NA	NA
BETA,M	0.0200	0.0200	0.0200	0.0200	0.0000	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M	73.07	73.20	74.20	74.30	72.04	NA	NA	NA	NA
PROJECTION TO ENGINE PARTICULATE:									
I.F. ENGINE IND. MCGRND (GEODGRAPH/MASO)	3.5	3.5	3.5	3.5	3.5	NA	NA	NA	NA
BETA,M,ENGINE	0.1335	0.1300	0.1305	0.1335	0.1335	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, TEST PRAC. EFF. AND I.F.ENG.	-1704	-2740	-2053	-3000	-1000	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M,ENGINE	30.14	35.25	30.40	30.04	35.02	NA	NA	NA	NA
INLET (DAMPLING) AND ESCAPE (DAMPLING):									
I.S. IND. MCGRND	10.5	10.7	10.5	13.0	15.0	NA	NA	NA	NA
E.S. IND. MCGRND	10.7	10.2	10.0	10.0	10.0	NA	NA	NA	NA
CALC. C.S. IND. MCGRND	10.5	10.5	10.1	13.7	15.0	NA	NA	NA	NA
ALPHA,M	0.0020	0.0040	0.0000	0.0370	0.0700	NA	NA	NA	NA
BETA,M	0.0413	0.0300	0.0070	0.0417	0.0000	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M	00.50	70.47	70.20	07.04	70.01	NA	NA	NA	NA
PROJECTION TO ENGINE PARTICULATE:									
I.F. ENGINE IND. MCGRND (GEODGRAPH/MASO)	3.5	3.5	3.5	3.5	3.5	NA	NA	NA	NA
BETA,M,ENGINE	0.1335	0.1335	0.1335	0.1335	0.1335	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, TEST PRAC. EFF. AND I.F.ENG.	45.00	-034	-320	-340	-330	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M,ENGINE	30.07	30.07	40.00	30.70	30.07	NA	NA	NA	NA
CATCH AND ESCAPE (DAMPLING):									
C IND. MCGRND	10.0	15.0	12.5	15.4	15.5	NA	NA	NA	NA
E.S. IND. MCGRND	10.0	15.2	10.0	10.0	15.7	NA	NA	NA	NA
CALC. I IND. MCGRND	10.7	15.1	10.0	10.0	15.0	NA	NA	NA	NA
ALPHA,M	0.0700	0.0744	0.0000	0.0751	0.0727	NA	NA	NA	NA
BETA,M	0.0000	0.0070	0.0000	0.0000	0.0000	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M	00.20	00.42	07.02	07.00	07.00	NA	NA	NA	NA
PROJECTION TO ENGINE PARTICULATE:									
I.F. ENGINE IND. MCGRND (GEODGRAPH/MASO)	3.5	3.5	3.5	3.5	3.5	NA	NA	NA	NA
BETA,M,ENGINE	0.1335	0.1335	0.1335	0.1335	0.1335	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, TEST PRAC. EFF. AND I.F.ENG.	22.25	20.45	22.00	10.70	20.40	NA	NA	NA	NA
COLLECTION EFFICIENCY, S, ALPHA,M AND BETA,M,ENGINE	30.07	35.70	40.00	30.02	34.04	NA	NA	NA	NA

TEST SERIES NUMBER
TEST NUMBER
TEST DATE
UPDATED/REVISED DATE
CYCLONE CONFIGURATION:

SERIES
DIAMETER, IN.
INLET CONFIGURATION
INLET AREA, SQ. FT.
VERTICAL MEASUREMENT LOCATION

TEST PARTICULATE:

MATERIAL
INTERNAL ISO, NUMBER
"PACCOAT" USED
"PACCOAT" ISO, NUMBER

TEST OPERATING CONDITIONS:

AIR FLOW, ACFM
AIR TEMPERATURE, F.
AIR DENSITY, LB./CU. FT.
CYCLONE INLET VELOCITY, FPM.
CYCLONE INLET UP, IN.W.G.
DELTA P, IN. TO OUT., WITH SPIN, IN.W.G.
DELTA P, IN. TO OUT., NO SPIN, IN.W.G.
DELTA P, IN. TO HOP., IN.W.G.
H, IN. TO OUT., WITH SPIN
H, IN. TO OUT., NO SPIN
H, IN. TO HOP.

PROJECT TO ENGINE GAS FLOW OPERATION:

GAS FLOW, ACFM
GAS TEMPERATURE, F.
GAS DENSITY, LB./CU. FT.
CYCLONE INLET VELOCITY, FPM.
CYCLONE INLET UP, IN.W.G.
DELTA P, IN. TO OUT., WITH SPIN, IN.W.G.
DELTA P, IN. TO OUT., NO SPIN, IN.W.G.
DELTA P, IN. TO HOP., IN.W.G.

FEED AND CATCH WEIGH DATA:

CYCLONE INLET PARTICULATE CONCENTRATION, GRAINS/ACF.
COLLECTION EFFICIENCY, % CE,W

INLET AND ESCAPE ISOTHERMIC SAMPLING DATA:

CYCLONE INLET PARTICULATE CONCENTRATION, GRAINS/ACF.
COLLECTION EFFICIENCY, % CE,S

PARTICULATE RECONSTRUCTION FROM COLLECTION HOPPER:

HOPPER .75 FULL:
L, C.E., SAMPLING, GRAINS/CU.FT.
ISO, C.E., HALVERN, MICROG.
HOPPER .50 FULL:
L, C.E., SAMPLING, GRAINS/CU.FT.
ISO, C.E., HALVERN, MICROG.
HOPPER .75 FULL:
L, C.E., SAMPLING, GRAINS/CU.FT.
ISO, C.E., HALVERN, MICROG.

FRACTIONAL EFFICIENCY BY GEOMETRIC ANALYSIS/METHOD, USING CE,S:

INLET (FEED) AND ESCAPE (SAMPLING):
I,F ISO, MICROG.
E,S ISO, MICROG.

014 014 014
014 015 016
05/25/00 05/25/00 05/25/00
05/10/00 05/10/00 05/10/00

200 200 200
0.5 0.5 0.5
JH MED. JH MED. JH MED.
.1504 .1504 .1504
OUT. COL. OUT. COL. OUT. COL.
(OUT) (OUT) (OUT)
SILICA SILICA SILICA
3.0 3.0 3.0
NA NA NA
NA NA NA

500 570 570
50 100 100
.0730 .0747 .075
02.72100 02.71007 04.00142
.0000 .0072 .0100
25.41 25.10 25.04
20.7 20.0 20.75
24.04 25.42 25.01
20.05 27.70 27.24
22.37 21.75 21.30
27.11 20.02 27.21

700 700 700
700 700 700
.0042072 .0042072 .0042072
77.57002 77.57002 77.57002
.0173000 .0173000 .0173000
17.00000 17.10000 16.01901
10.00304 10.00225 10.31200
10.73755 17.20007 10.70020

NA NA NA
NA NA NA
NA NA NA
NA NA NA

0.0300 NA NA
15.5 NA NA
NA 0.0313 NA
NA 15.5 NA
NA NA 0.0423
NA NA 15.3

NA NA NA
NA NA NA

015 015 015
017 018 019
05/20/00 05/20/00 05/20/00
05/10/00 05/10/00 05/10/00

200 200 200
0.5 0.5 0.5
JH MED. JH MED. JH MED.
.1504 .1504 .1504
OUT. OUT. OUT. OUT. OUT. OUT.
SILICA SILICA SILICA
3.0 3.0 3.0
NA NA NA
NA NA NA

572 500 570
57 50 50
.0701 .0704 .070
02.50002 02.05400 02.40704
.0004 .0000 .0000
20.02 20.00 20.70
20.3 20.30 20.20
10.4 10.20 10.01
20.9 20.00 20.00
20.00 20.77 20.0
20.30 20.30 20.00

700 700 700
700 700 700
.0042072 .0042072 .0042072
77.57002 77.57002 77.57002
.0173000 .0173000 .0173000
10.21312 10.42021 10.20000
20.70300 20.04000 20.00000
12.50000 12.50000 12.71214

NA NA NA
NA NA NA
NA NA NA
NA NA NA

0.0005 NA NA
20.5 NA NA
NA 0.0000 NA
NA 10.5 NA
NA NA 0.0072
NA NA 10.7

NA NA NA
NA NA NA

016 017
000 001
05/01/00 05/10/00
05/22/00 05/22/00

200 200
0.5 0.5
JH MED. JH MED.
.1504 .1504
H WINDS H WINDS
OUT. OUT. OUT.
SILICA SILICA
3.0 3.0
NA NA
NA NA

500 570
100 110
.0757 .0700
02.72100 04.10200
.0000 .0000
25.40 20.10
25.01 20.00
25.2 20
20.00 27.07
22.10 21.77
20.00 21.00

700 700
700 700
.0042072 .0042072
77.57002 77.57002
.0173000 .0173000
17.00000 17.00000
10.00000 10.00070
10.00000 12.57002

1.00 0.00
02.32 00.00
0.30 0.37
20.37 20.70

NA NA
NA NA
NA NA
NA NA
NA NA
NA NA

3.0 3.0
0.0 NA

CALC. C.F. IND. NOCHENS	NA	NA	NA	NA	NA	NA	0.7	NA
ALPHA.W	NA	NA	NA	NA	NA	NA	0.2010	NA
BETA.W	NA	NA	NA	NA	NA	NA	0.1074	NA
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W	NA	NA	NA	NA	NA	NA	51.00	NA
PROJECTION TO ENGINE PARTICULARS:								
I.F. ENGINE IND. NOCHENS (GEOMETRY/MASS)	NA	NA	NA	NA	NA	NA	3.0	3.0
BETA.W. ENGINE	NA	NA	NA	NA	NA	NA	0.1000	0.1000
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.F. ENG.	NA	NA	NA	NA	NA	NA	70.00	NA
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W. ENGINE	NA	NA	NA	NA	NA	NA	60.00	NA
PROJECTION TO ENGINE OPERATION:								
CYCLONE DIAMETER, INCHES	NA	NA	NA	NA	NA	NA	0.7	NA
ALPHA. ENGINE	NA	NA	NA	NA	NA	NA	0.1000	NA
COLLECTION EFFICIENCY, S. ALPHA. ENGINE & BETA. ENGINE	NA	NA	NA	NA	NA	NA	50.00	NA
COLLECTION EFFICIENCY, S. F.E., ENGINE & I. F. ENGINE	NA	NA	NA	NA	NA	NA	70.01	NA
INLET (SAMPLING) AND ESCAPE (SAMPLING):								
I.S. IND. NOCHENS	NA	NA	NA	NA	NA	NA	NA	NA
E.S. IND. NOCHENS	NA	NA	NA	NA	NA	NA	0.0	NA
CALC. C.S. IND. NOCHENS	NA	NA	NA	NA	NA	NA	NA	NA
ALPHA.W	NA	NA	NA	NA	NA	NA	NA	NA
BETA.W	NA	NA	NA	NA	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W	NA	NA	NA	NA	NA	NA	NA	NA
PROJECTION TO ENGINE PARTICULARS:								
I.F. ENGINE IND. NOCHENS (GEOMETRY/MASS)	NA	NA	NA	NA	NA	NA	3.0	3.0
BETA.W. ENGINE	NA	NA	NA	NA	NA	NA	0.1000	0.1000
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.F. ENG.	NA	NA	NA	NA	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W. ENGINE	NA	NA	NA	NA	NA	NA	NA	NA
PROJECTION TO ENGINE OPERATION:								
CYCLONE DIAMETER, INCHES	NA	NA	NA	NA	NA	NA	0.7	NA
ALPHA. ENGINE	NA	NA	NA	NA	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. ALPHA. ENGINE & BETA. ENGINE	NA	NA	NA	NA	NA	NA	NA	NA
COLLECTION EFFICIENCY, S. F.E., ENGINE & I. F. ENGINE	NA	NA	NA	NA	NA	NA	NA	NA
CATCH AND ESCAPE (SAMPLING):								
C. IND. NOCHENS	NA	NA	NA	NA	NA	NA	0.4	NA
E.S. IND. NOCHENS	NA	NA	NA	NA	NA	NA	0.0	NA
CALC. I. IND. NOCHENS	NA	NA	NA	NA	NA	NA	2.0	NA
ALPHA.W	NA	NA	NA	NA	NA	NA	0.2720	NA
BETA.W	NA	NA	NA	NA	NA	NA	0.2000	NA
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W	NA	NA	NA	NA	NA	NA	50.00	NA
PROJECTION TO ENGINE PARTICULARS:								
I.F. ENGINE IND. NOCHENS (GEOMETRY/MASS)	NA	NA	NA	NA	NA	NA	3.0	3.0
BETA.W. ENGINE	NA	NA	NA	NA	NA	NA	0.1000	0.1000
COLLECTION EFFICIENCY, S. TEST PRAC. EFF. AND I.F. ENG.	NA	NA	NA	NA	NA	NA	60.00	NA
COLLECTION EFFICIENCY, S. ALPHA.W AND BETA.W. ENGINE	NA	NA	NA	NA	NA	NA	70.00	NA
PROJECTION TO ENGINE OPERATION:								
CYCLONE DIAMETER, INCHES	NA	NA	NA	NA	NA	NA	0.7	NA
ALPHA. ENGINE	NA	NA	NA	NA	NA	NA	0.2100	NA
COLLECTION EFFICIENCY, S. ALPHA. ENGINE & BETA. ENGINE	NA	NA	NA	NA	NA	NA	70.00	NA
COLLECTION EFFICIENCY, S. F.E., ENGINE & I. F. ENGINE	NA	NA	NA	NA	NA	NA	70.00	NA

FRACTIONAL EFFICIENCY BY HALVERN ANALYSIS/MASS. USING CE.S:

INLET (FEED) AND ESCAPE (SAMPLING):							10.0	NA
I.F. IND. NOCHENS	NA	NA	NA	NA	NA	NA	10.0	NA
E.S. IND. NOCHENS	NA	NA	NA	NA	NA	NA	17.0	NA
CALC. C.F. IND. NOCHENS	NA	NA	NA	NA	NA	NA	0.0047	NA
ALPHA.W	NA	NA	NA	NA	NA	NA		

BETA.W	NA	NA	NA	NA	NA	NA	0.0000	NA
COLLECTION EFFICIENCY, S, ALPHA.W AND BETA.W	NA	NA	NA	NA	NA	NA	70.00	NA
PROJECTION TO ENGINE PARTICULATE:								
I.P.ENGINE IND. NOISE (SOUNDPOWER/HAZ)	NA	NA	NA	NA	NA	NA	3.9	3.9
BETA.W.ENGINE	NA	NA	NA	NA	NA	NA	0.1000	0.1000
COLLECTION EFFICIENCY, S, TEST PROC. EFF. AND I.P.ENG.	NA	NA	NA	NA	NA	NA	-10.00	NA
COLLECTION EFFICIENCY, S, ALPHA.W AND BETA.W.ENGINE	NA	NA	NA	NA	NA	NA	32.00	NA
INLET (SAMPLING) AND ESCAPE (SAMPLING):								
I.S IND. NOISE	NA	NA	NA	NA	NA	NA	13.0	NA
E.S IND. NOISE	NA	NA	NA	NA	NA	NA	19.0	NA
CALC. C.S IND. NOISE	NA	NA	NA	NA	NA	NA	12.0	NA
ALPHA.W	NA	NA	NA	NA	NA	NA	0.0000	NA
BETA.W	NA	NA	NA	NA	NA	NA	0.0000	NA
COLLECTION EFFICIENCY, S, ALPHA.W AND BETA.W	NA	NA	NA	NA	NA	NA	00.00	NA
PROJECTION TO ENGINE PARTICULATE:								
I.P.ENGINE IND. NOISE (SOUNDPOWER/HAZ)	NA	NA	NA	NA	NA	NA	3.9	3.9
BETA.W.ENGINE	NA	NA	NA	NA	NA	NA	0.1000	0.1000
COLLECTION EFFICIENCY, S, TEST PROC. EFF. AND I.P.ENG.	NA	NA	NA	NA	NA	NA	50.30	NA
COLLECTION EFFICIENCY, S, ALPHA.W AND BETA.W.ENGINE	NA	NA	NA	NA	NA	NA	30.01	NA
CATCH AND ESCAPE (SAMPLING):								
C IND. NOISE	NA	NA	NA	NA	NA	NA	13.7	NA
E.S IND. NOISE	NA	NA	NA	NA	NA	NA	19.0	NA
CALC. I IND. NOISE	NA	NA	NA	NA	NA	NA	14.4	NA
ALPHA.W	NA	NA	NA	NA	NA	NA	0.0720	NA
BETA.W	NA	NA	NA	NA	NA	NA	0.0021	NA
COLLECTION EFFICIENCY, S, ALPHA.W AND BETA.W	NA	NA	NA	NA	NA	NA	01.30	NA
PROJECTION TO ENGINE PARTICULATE:								
I.P.ENGINE IND. NOISE (SOUNDPOWER/HAZ)	NA	NA	NA	NA	NA	NA	3.9	3.9
BETA.W.ENGINE	NA	NA	NA	NA	NA	NA	0.1000	0.1000
COLLECTION EFFICIENCY, S, TEST PROC. EFF. AND I.P.ENG.	NA	NA	NA	NA	NA	NA	30.40	NA
COLLECTION EFFICIENCY, S, ALPHA.W AND BETA.W.ENGINE	NA	NA	NA	NA	NA	NA	30.22	NA

 * FIGURE 2A-14 *

(8) - 1/2" HOLES
 OR (8) - 3/8" X 1 1/2" LG.
 HEX HD. BOLTS WITH NUTS

(4) - 1/2" HOLES
 OR (4) - 3/8" X 1 1/2" LG.
 HEX HD. BOLTS WITH NUTS

$$\Delta R_T = 0.75"$$

$$\Delta R_M = 0.47"$$

$$\Delta R_B = 0.19"$$

(4) - 1/2" HOLES
 OR (4) - 3/8" X 1 1/2" LG.
 HEX HD. BOLTS WITH NUTS

TAB 3

DOE/NETS TOPICAL REPORT
CHAPTER 2B

CHAPTER 2B

Commensurate with Task 2, Emissions Applied R&D.

Task 2.2.1 & 2.2.2

Laboratory cold flow testing of various candidate Emissions Control Concepts

Envelope Type Barrier Filter

Introduction

Previous program tasks had identified the Barrier Filter as the control concept most likely to satisfy program objectives of particulate collection and, by the use of an appropriate sorbent material, reduction of undesired gases in the engine exhaust effluent. Although ongoing testing was in progress at the 10 ACFM slipstream from the CWS fuel research diesel engine for the purpose of investigation of alternative filter media and sorbents, a filter media consisting of a metallic fiber composite was selected for the design of a 500 ACFM cold flow test facility. Eventual design of a 20,000 ACFM capacity filter for a full size CWS fuel diesel engine, which could be operated at severe filtration velocity within the space constraints required for installation on a locomotive, required a creative design configuration for the application of the filter media. All of these requirements were best served by a design comprising closely spaced, two-sided panels of filter media in an envelope configuration.

Test Facility

The Envelope Filter designed for cold flow operation in the GEESI laboratory is described by GEESI Drawings S9513/FA 800 through 807 and 810. These drawings are enclosed in Appendix 2B.

Features of this design concept are discussed as follows:

Four double-sided filter envelopes with dimensions of 2'-10" X 2'-2" produced a total filtration area of 50 sq ft. Particulate was collected on the outside surface of the filters, in accordance with the convention used for pulse jet type cleaned fabric filters. Filter thickness was 1 inch and envelope spacing was 3 inches resulting in a 2 inch space between the installed envelopes.

The filter casing was designed to permit varied gas flow direction configurations, top inlet/side outlet and side inlet/top outlet. Filter casing width was greater than required for the designed envelope spacing in the event expanded spacing was found to be required.

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Filter envelope construction consisted of a perimeter frame to which the filter media was attached using bolted overlay flanges. Use of available filter media necessitated attachment of the filter media in two half panel size pieces. Filter frames were constructed in several versions of subdivision sizes of back-up and overlay flanges, relative to filtration gas flow and reverse gas flow cleaning directions.

Cleaning of the filters was by reverse air flow pulsing using a 3/4 inch diameter pulse air manifold located outside of the envelope air flow discharge flange. Filter cleaning pulse air flow was discharged through a series of small diameter holes (3/16 inch, 1/4 inch, and 5/16 inch) located along the length of the manifold. Pulse air operation was designed to replicate conventional pulse jet type fabric filtration using a fast acting solenoid operated valve.

Pulse valve operation control was by a conventional pulse jet fabric filter controller which could be adjusted for ontime-duration of air pulse, conventionally operated at a time interval of approximately 0.1 second; offtime-time interval between pulses; high pressure set point-filter pressure drop at initiation of cleaning; low pressure set point-filter pressure drop at termination of cleaning.

As designed, filter inlet plenum included two perforated plates to distribute filter inlet air flow to the envelopes. Three types of filter media which was procured for various uses and planned for initial Envelope Filter test use were 1) Fluid Dynamics vendor, stainless steel fiber composite, 1 micron porosity; 2) Bekipore vendor, stainless steel fiber composite, 5 micron porosity; and 3) Bekipore vendor, Inconel fiber composite, 12 micron porosity.

Test Operating Conditions

Planned test particulate operation included the use of 3.7 micron MMD pulverized silica to simulate CWS fuel diesel engine particulate. However, previous single cylinder CWS fuel diesel engine slipstream tests had indicated that collection of the exhaust gas particulate on a barrier filter did not permit effective cleaning of the filter media. However, when the exhaust particulate was collected upon a previously deposited precoat particulate material, cleaning was much improved.

Therefore, the planned operation of the Envelope Filter media was designed to include continuous injection of precoat material to maintain a favorable environment for filter cleaning. Material selected for this precoat function was Alumina powder with an MMD of 52 microns, as illustrated by Appendix Figure 2A-2.

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Test particulate operation of the Envelope Filter was planned to be a 5:1 ratio of precoat material to CWS fuel ash particulate, resulting in a filter inlet particulate concentration of approximately 6 grains/acf. This operating condition included approximately 1 grain/acf of simulated CWS fuel ash particulate.

Conceptual operation of a full size Envelope Filter installed on a locomotive was perceived to be restricted to a pressure drop of 20 IWG, as a practical limitation of engine turbocharger backpressure. Although replication of this pressure drop at ambient temperature air cold flow operation would have required a filter media and particulate filter cake pressure drop of approximately 44 IWG, this test operating condition was perceived to be impractical, and the laboratory test facility was designed for a maximum pressure drop limited to 20 IWG. Therefore, the amount of filter cake deposited on the filter media during laboratory cold flow testing was less than would occur during comparable hot gas operation.

Preliminary Operation

The initial configuration of the Envelope Filter for testing was the Top inlet/Side outlet arrangement which was perceived to be an optimum configuration for the planned high filtration velocity operating condition. Initial assembly of the filter envelopes was with the Fluid Dynamics 1 micron porosity filter media. Installation of the filter media onto the envelope frames was with use of the maximum open geometry frame configuration consisting of two-panel subdivisions for both the filtration and reverse pulse air cleaning directions. It was noted that the filter media did not lie perfectly flat on the frames and had the ability for "oil can" type movement which was thought to be desirable for effective removal of the filter cake particulate.

The filter was assembled for operation except for the outlet plenum which permitted direct observation of the filter envelopes during filtration and cleaning operation. During filtration operation, it was noted that the combination of the "oil can" characteristic of the filter media and the open geometry of the envelope frames allowed the filter media to excessively deflect toward the inside of the envelopes to a point of almost touching. This condition was not judged to be a satisfactory situation and the envelope configuration was changed to a closed geometry consisting of eight-panel subdivisions for the filtration gas flow direction. The previous two-panel subdivision geometry was retained for the reverse pulse air flow direction.

Figures 2B-1 and 2B-2 illustrate Envelope filter pressure drop characteristics for air flow operation without and with filter media installed on the filter frames. These graphs illustrate that the major source of the Envelope Filter pressure drop was the filter media. A F/F filter pressure drop of 3.4 IWG was indicated for the Neld Filter Media at 500 ACFM air flow.

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Several Preliminary Tests 001 to 006 were performed to prove operation of test facility components. Test operating conditions and test observations are illustrated by Table 2B-1. Results of Tests 005 and 006 are illustrated by Figures 2B-3 and 2B-4 which are graphs of Envelope Filter inlet flange to outlet flange, F/F, filter pressure drop and filtration velocity during the test runs.

After completion of Test 006, the envelopes were removed for inspection. Each of the envelopes showed indication of particulate leakage because of incomplete seal welding of the envelope frames. This problem was temporarily repaired by use of silicone caulking, and the filter was reassembled for further testing. A test plan of 10 tests, Tests 007 through 016, was set to explore all of the major operating condition variables of Envelope Filter operation, as illustrated by Figure 2B-5.

Figure 2B-6 is a detailed summary of test operating conditions and test results for 14 tests, Tests 007 through 012 and Tests 101 through 106. All tests were performed with the same configuration of filter casing and filter envelopes tested for the Preliminary tests. Also, all tests employed the same test particulate operating conditions of Precoat exhaust particulate ratio = 5:1 and approximately 6 grains/acf filter inlet test particulate concentration. However, test conditions were varied in regard to test operation variables as follows:

- Filter test air flow, ACFM (all tests except 106 at approximately 400 ACFM)
- Filter filtration velocity, FPM (all tests except 106 at approximately 8 FPM)
- Air pulse pressure, PSIG
- Air pulse ontime, sec
- Air pulse offtime, sec
- High pressure drop set point, IWG
- Low pressure drop set point, IWG

Test results are also summarized by Figures 2B-7 through 2B-15 for Tests 007 through 012, respectively, in chronological order. Figures illustrate test results of F/F filter pressure drop, IWG, and filter operation filtration velocity (A/C), FPM. Figure subtitles summarize pertinent operating conditions, such as Test number, Filter media, Filter air flow ACFM, Filter media filtration velocity FPM, Pulse pressure PSIG, Pulse ontime m seconds, Pulse offtime seconds, High pressure drop set point IWG, Low pressure drop set point IWG, and Mixture ratio of sorbent/precoat particulate (SP): Exhaust particulate (EP).

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Discussion of Test Results for Tests 007 to 016

Tests 007 and 010 were performed using 80 PSIG pulse air pressure and pulse ontimes of 55 and 100 m seconds, respectively. These tests were unable to achieve equilibrium filter pressure drop less than the 15 IWG high pressure drop set point when operating in continuous cleaning. Therefore, most subsequent tests were performed with pulse air pressure increased to 100 PSIG.

Tests 11, 11A, and 11B were performed at 100 PSIG pulse air pressure and 55 m second pulse ontime. Each test was able to sustain equilibrium filter pressure drop less than a 15 IWG high pressure drop set point. Although Tests 11 and 11A were operated in continuous cleaning, Test 11B operated at cyclic cleaning between the 15 IWG and 11 IWG high and low pressure drop set points. However, Test 11B did appear to be approaching a continuous cleaning operating condition.

Test 016 was operated at the same conditions as tests 11, 11A, and 11B. This test began operating in cyclic cleaning between 12 IWG and 10 IWG high and low set points. However, operation degenerated to continuous cleaning at a pressure drop less than the 12 IWG high pressure drop set point, but was increasing when the test was terminated.

Test 008 was also performed at 100 PSIG and 55 m second operating conditions with high and low pressure drop set points of 20 and 15 IWG, respectively. This test sustained stable pressure drop operation between the high and low set points while operating in cyclonic cleaning operation.

Test 009 operating conditions were the same as for Test 008, except that the low pressure drop set point was changed to 18 IWG. This test also produced stable equilibrium pressure drop operation between the high and low pressure drop set points, while operating in cyclonic cleaning.

Test 012 again attempted operation at pulse air pressure less than 100 PSIG. Test operation was started at 60 PSIG, which produced uncontrolled filter pressure drop. Pulse air pressure was increased in steps to 100 PSIG. At this condition, filter pressure drop was again stable and controlled in equilibrium between the 20 and 18 high and low pressure drop set points, by cyclonic cleaning operation.

Figures 2B-16 through 2B-20 summarize filtration velocity and pressure drop test results for Tests 101 through 106.

Test 101 duplicated the favorable test operating conditions and test results of Tests 009 and 012, with the exception that the test particulate was made more favorable by deletion of the fine test particulate which simulated the 3.7 micron MMD exhaust gas particulate.

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Test results were again stable and ranged between the 20 IWG and 18 IWG high and low pressure drop set points, while operating in cyclonic cleaning. The results of this test are also noteworthy in regard to a longer test duration than Tests 009 and 012, and less rapid pressure drop rise between cleaning cycles.

Test 102 was planned as an exact duplication of Tests 009 and 012. For five cleaning cycles, test results were again stable and filter pressure drop was between the 20 IWG and 18 IWG pressure drop set points. However, after the fifth cleaning cycle, filter cleaning ceased to be effective and pressure drop became uncontrolled under continuous cleaning operation. The phenomenon for this change was not understood.

Test 013 was another planned duplication of Tests 009 and 012, except that the filter cleaning operation was enhanced by increasing ontime from 55 to 100 m seconds. Once again, cleaning was effective for several cleaning cycles, but then became less effective and eventually operation reverted to continuous cleaning resulting in uncontrolled filter pressure drop.

Test 104 was similar to Test 012, as test operation was started at a pulse air pressure of 90 PSIG. Filter pressure drop was immediately out of control, and an increase of the pulse air pressure to 100 PSIG was unable to improve operation, as the filter continued to operate in continuous cleaning.

For Test 106, filter operation was altered by a reduction of air flow to 322 ACFM corresponding to a filtration velocity of 6.4 FPS. Commensurate with this operating condition was a change of the high and low pressure drop set points from 20 and 18 IWG to 12 and 10 IWG, as employed for the previous series of tests. Operation of the filter did sustain two cyclonic cleaning cycles before reverting to continuous cleaning. However, filter pressure drop did remain within the range of 12 to 10 IWG.

While performing the previously described series of 14 tests without air flow in operation, filters were thoroughly cleaned by "off line" cleaning between each test. However, there occurred a general trend of increasing test start pressure drop. This was suspected to be caused by increased particulate blinding of the filter media.

Isokinetic sampling of the filter effluent indicated very favorable Collection Efficiency for the initial series of tests, better than 99.99%, but degenerating to 99.72% by the final test. This change was suspected to be indicative of a failure of the repair of the filter envelope frames or some other failure of the filter media.

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A further observation performed during the series of tests was observation of the test particulate delivery to the filter envelopes by use of the windows located in the filter casing. There was an observation of upward movement of particulate, especially at the bottom of the envelopes. This condition was concluded to be indicative of ineffective air flow distribution to the envelopes, which could result in a failure of the particulate to settle in the collection hopper and a disruption of effective filter cleaning.

Repair and Upgrade of Envelope Filter Test Facility

After completing Tests 007 to 106, the envelopes were removed from the Envelope Filter casing for inspection for evidence of blinding and for evidence of leakage of the envelope frames or of the 1 micron porosity Fluid Dynamics filter media. It was determined that the filter media had failed at several locations adjacent to the envelope filter perimeter frame bolted overlay flange. All failures occurred on envelopes in the region opposite to the end where the pulse air was delivered, a location which was suspected to be subject to the most intense cleaning action. It was apparent that the failures had occurred in the direction of reverse flow cleaning operation. These failures were examined by the filter media supplier (Fluid Dynamics), who advised that the pulse air operation - 100 PSIG was excessive for the design of the filter media backup support in the reverse flow direction. Plans were made to have supplied improved replacement filter media, as follows:

Greater than 1 micron porosity to be less subject to blinding.

1 micron porosity, but constructed with additional internal reinforcement to permit use of the existing envelope filter media backup support design.

This temporary interruption of Envelope Filter test operation provided an opportunity to investigate air flow distribution in the filter casing, as well as particulate delivery to the envelopes. These investigations were performed using the damaged filter media envelopes, which were satisfactory for the air flow only test procedure.

Figure 2B-21 sketch illustrates the location velocity traverses performed at the top air flow approach to the filter envelopes from the filter inlet plenum. This location represented the maximum approach velocity, before any air flow had entered the envelopes. Velocity traverses were also performed at the bottom of the envelopes, at a location where all of the air flow should have entered the envelopes and where there should not be any indication of air flow external to the envelopes. Test instrumentation used for these tests was a thermal (hotwire) anemometer.

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Two situations gave concern regarding uniform velocity distribution of air flow approach to the envelopes, as well as positive "downflow" of air flow extending to the bottom of the envelopes. One concern was created by the unoccupied space at the sides of the filter to permit wider spacing of the envelopes, if required. This condition could permit a net "downflow" into the hopper region resulting in undesirable "upflow" in other regions of the filter casing. Another concern was related to possible insufficient attention given to air flow distribution devices located in the filter inlet plenum.

An initial velocity distribution test confirmed failure to achieve the desired "downflow" characteristic. Figure 2B-22 Velocity profile graph Test "2", top of envelopes, illustrates a velocity gradient ranging between +0.6 Average V at the approach duct end of the plenum to +2.3 Average V at the opposite far end of the plenum. Figure 2B-23 Velocity profile graph Test "2", bottom of envelopes, illustrates the resulting serious maldistribution of air flow at the bottom of the envelopes. Velocity in the approach duct end of the filter indicated -5.9 Average V in an undesired "upflow" direction, while the opposite end of the filter evidenced +7.7 Average V in a "downflow" direction. However, there was no significant indication of net "upflow" created to the side-to-side direction of the filter.

These test results were concluded to be an unsatisfactory representation of the desired "downflow" characteristic.

Gas flow devices were installed in the filter casing and in the ductwork, as illustrated by sketches in Figures 2B-21 and 2B-24. Velocity distribution tests were again performed, as illustrated by Figures 2B-25 and 2B-26 Test "4" velocity profile graphs. At the approach to the envelopes, end-to-end velocity distribution at the top of the envelopes ranged between +0.7 and +1.4 Average V. These results were concluded to be satisfactory. At the bottom of the envelopes, all velocity measurements depicted "downflow". End-to-end averages ranged between +0.7 and +1.3 Average V. These results were likewise concluded to represent satisfactory operation. Although the quantification of these velocity measurements may be suspect because of the magnitude and complexity of the flow field, the confirmation of consistent "downflow" was conclusive.

Reactivation of filter media testing was executed by installation of increased porosity filter media which was supplied by vendor Bekipore. Envelope configurations were variable, as follows:

Envelope "A", left side outboard - Bekipore Inconnel fiber, 12 micron porosity, filtration direction air flow support = 2X4 matrix, reverse direction air flow support = 1X2 matrix.

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Envelope "B", right side inboard - Bekipore stainless steel fiber 5 micron porosity, filtration direction air flow support = 2X4, reverse direction air flow support = 1X2 matrix.

Envelope "C", right side inboard - Bekipore Inconel fiber, 12 micron porosity, filtration direction air flow support = 2X4 matrix, reverse direction air flow support = 1X1 matrix.

Envelope "D", right side outboard - Bekipore stainless steel fiber, 5 micron porosity, filtration direction air flow direction = 2X4 matrix, reverse direction air flow = 1X1 matrix.

Figure 2B-27 for Test 002/107 illustrates the composite pressure drop characteristic of the newly installed composite of Bekipore 12 micron and 5 micron porosity filter media. An F/F pressure drop of 0.1 IWG at 500 ACFM operation is contrasted to a pressure drop of 3.4 IWG for the previously tested Fluid Dynamics 1 micron porosity filter media.

Revised Envelope Filter Configuration and Revised Test Conditions

A test program was undertaken to determine the cleanability of the newly installed increased porosity composite filter media when operating with modified pulse air conditions consisting of much reduced pulse air pressure, relative to the 100 PSIG pressure used to clean the previously tested Fluid Dynamics 1 micron porosity filter media. Simultaneous with the pressure change was another change to extend the time duration of the ontime during which the pulse cleaning is in operation. With a planned reduction of pulse air pressure and subsequent reduced reduction of stressing the filter media during cleaning, it was possible to reduce the amount of backup support in the reverse flow cleaning direction. Therefore, two of the envelopes were constructed with a 1X1 support matrix instead of the previously tested 1X2 matrix. The purpose of this change was to provide additional flexibility of the filter media when being cleaned to enhance removal of collected particulate.

A change was also made to the test procedure in regard to the mixture of Sorbent/Precoat (SP): (simulated) Exhaust Particulate (EP). Previous tests had used a particulate concentration of 6 grains/acf of 5:1 SP:EP ratio. In consideration that exhaust particulate emissions were really more in the order of 0.2 grains/acf, the test particulate material was altered to a SP:EP ratio of 5:0.2 and operated at a particulate concentration of approximately 5 grains/acf. Another test operating condition change was the use of "Neutralite" filter media precoat material. "Neutralite" is a commercial product used for precoating fabric filters for difficult filtration applications. This material is a fine powder of Aluminum Silicate with a MMD of 5 microns, as illustrated by Figure 2B-28.

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Another operating condition change was in regard to the method of controlling the envelope cleaning. Previous testing had employed high and low pressure drop set points to control the cyclic range of pressure drop. The revised procedure used only a high pressure drop cleaning initiation set point and deactivation of the low pressure drop set point. This was to cause cleaning to become continuous in an effort to obtain more consistent sorbent coating on the filter media.

Other than these discussed test procedure changes, all other test procedures were the same as employed for the previous test programs.

Discussion of Test Results

Test 108 was conducted at an air flow of 400 ACFM corresponding to a filtration velocity of 8.0 FPM. This test investigated the effect of pulse air pressure (40 to 35 PSIG) and pulse duration ontime (1.1 to 0.6 seconds) variables upon cleanability of the filter media. Test results are illustrated by Table 2B-2, Summary of Test Conditions and Test Results, and by Figure 2B-29, which illustrates test operation pressure drop vs. test time. These illustrations show that the filters were cleaned from a 5 IWG initiation of cleaning to a pressure drop range of 0.8 to 2.3 IWG, depending on the cleaning operating conditions. A reduction of the ontime from 1.1 seconds to 0.6 seconds and reduction of pulse air pressure from 40 PSIG to 35 PSIG both had the effect of reducing filter cleaning effectiveness. The test results indicated that equilibrium pressure drop could be sustained for operation at favorable 400 ACFM, 8.0 FPM air flow conditions.

Test 109 was conducted at constant operating conditions of 507 ACFM, 10.14 FPM air flow, and 0.6 seconds pulse ontime. The test operation variable was air pulse pressure, which ranged from 35 PSIG to 50 PSIG. Effective filter cleaning was achieved at this less favorable air flow operating condition. Cleandown pressure drop varied between approximately 5.5 and 8.0 IWG from a 10.0 IWG initiation of cleaning pressure drop. This variation was determined to be a function of relative cleanability of the different envelope filter media configurations. However, it was inconclusive as to which was the most or least favorable envelope configuration.

Test 110 was also conducted at 500 ACFM, 10.0 FPM air flow operation, and explored variables of pulse air pressure (45 to 55 PSIG) and pulse ontime (1.0 to 0.064 seconds). All test results represented equilibrium filter pressure drop operation. However, less effective cleaning was obtained as pulse ontime was decreased from 1.0 to 0.2 seconds while pulse pressure remained constant at 50 PSIG. When operating at 0.2 seconds ontime, cleaning was improved when pulse pressure was increased from 50 to 55 PSIG. When ontime was reduced to only 0.064 seconds at 55 PSIG pulse pressure, there was no great loss of cleaning effectiveness. This indicated that pulse ontime was not critical, if sufficiently high pulse pressure was used.

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Test 111 was operated at an extreme air flow condition of 600 ACFM, 12.0 FPM. Both pulse pressure and pulse ontime were again test variables. Once again, equilibrium filter pressure drop was attained, but it was necessary to use higher pulse pressure and longer pulse ontime for this more severe air flow operating condition.

Test 112 investigated pulse ontime and pulse pressure as variables at 400 ACFM, 8.0 FPM air flow operation. This test again produced equilibrium filter pressure drop and indicated the benefit of pulse air pressure increased from 50 PSIG to 55 PSIG. Also illustrated was continued satisfactory operation when pulse ontime was reduced from 1.0 to 0.65 seconds, while pulse pressure was maintained at 55 PSIG.

Test 114 considered air flow, pulse pressure, and pulse ontime as test variables. All test conditions achieved satisfactory equilibrium pressure drop, but most effective filter cleaning was obtained at the more favorable 400 ACFM, 8.0 FPM operating condition. Less favorable cleaning was obtained at 500 ACFM and 600 ACFM air flow operation, and it was necessary to increase pulse air pressure.

Test 115 investigated filter operation at very favorable air flow operation of 300 ACFM, 6.0 FPM. Most satisfactory operation was obtained at 60 PSIG pulse pressure, which permitted operation at pulse ontime as short as 0.1 seconds. Another different operating condition used for this test was the use of pulverized coal fuel boiler fly ash as the test particulate. This fly ash had an MMD of 34 microns, as illustrated by Figure 2B-36, which was finer than the approximately 52 micron MMD Alumina:Silica simulation of SP:EP test particulate used for previous tests.

Test 119 investigated all operating conditions as variables. Test particulate for this investigation was a finer pulverized coal fly ash with an MMD of 15.5 microns, as illustrated by Figure 2B-38. Although all test results indicate satisfactory equilibrium filter pressure drop, the most favorable test results were obtained at the more favorable 400 ACFM, 8.0 FPM air flow operating condition.

After completion of Test 119, an investigation was performed to characterize particulate distribution to the envelope filters. Before performing offline cleaning to aggressively clean the filters in preparation for the next test, one envelope, Envelope "D", consisting of 5 micron porosity filter media, and a 1X1 matrix of filter media support in the reverse gas flow direction, was removed and filter cake was sampled at four quadrants. As described by Figure 2B-38, particle size differences occurred at the varied locations, as follows:

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Test particulate MMD, microns	15.5
Gas flow approach side, Top of filter MMD, microns	19.5
Gas flow approach side, Bottom of filter MMD, microns	14.8
Gas flow exit side, Top of filter MMD, microns	9.1
Gas flow exit side, Bottom of filter MMD, microns	8.9

These results lead to a conclusion that particulate, and, therefore, gas flow, as well, were not uniformly distributed to the filter media for the design of the filter media, filter casing, and ductwork configuration, and the gas flow and particulate operating conditions.

Test 120 was performed again using a mixture of Alumina and Silica powders to simulate Sorbent/Precoat and Exhaust Particulate. However, this mixture contained less simulated Sorbent/Precoat and the test particulate concentration was approximately half of previous test operating conditions. Constant test operating conditions were 500 ACFM, 10.0 FPM air flow operation, and 0.2 second pulse ontime. The test variable was air pulse pressure, which ranged from 50 PSIG to 60 PSIG. The test results illustrate improved filter cleaning as pulse pressure was increased.

The results of Test 118 are illustrated by Figure 2B-41. This test result was a composite of Tests 113, 116, and 118, and represented the pressure drop characteristic of the composite configuration of filter media which was used for Tests 107 through 120. At each stage of the program, the filter media was returned to a "cleaned" condition by intense offline cleaning at the completion of each respective test. An interum cleaning was performed at a pulse pressure of 15 PSIG for comparison to a final cleaning performed at 50 PSIG. A history of the characteristics of the filter media is illustrated by the following tests:

- New filter media, Test 107
- Cleaned filter media, after completion of Test 112 (no mark)
- Cleaned filter media, after completion of Test 115 (mark II)
- Cleaned filter media, after completion of Test 117 (mark III)

These test results illustrate that 50 PSIG pulse air pressure was more effective than 15 PSIG for the removal of particulate entrapped within the filter media matrix. The test results also illustrate that blinding of the filter media, caused by particulate entrapped within the filter media matrix, increased as more filtration tests were performed. This characteristic was indicative of suspect suitability of the composite tested filter media for long term use. Although the filter media had displayed satisfactory filtration characteristics, the material did illustrate potential degradation relative to operation pressure drop.

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At the completion of this phase of the test program, the envelopes were removed for inspection of the filter media. All filters appeared to be in good condition with no evidence of failure such as had occurred with the previously tested Fluid Dynamics 1 micron porosity filter media.

Modified Envelope Configuration with New Fluid Dynamics Filter Media Installed

After completion of the previously reported test results using a composite of two different porosity Bekipore filter media, the Envelope Filter was rebuilt for another series of tests. Two new filter media were supplied by Fluid Dynamics. Media F187 had a porosity rating of 10 to 12 microns and E836 had a porosity rating of 5 to 6 microns. For an initial testing configuration, the 10 to 12 micron porosity filter media was installed on all four envelopes. Also, all envelope frames were reconstructed. Previous design envelope frames consisted of a perimeter frame constructed of flat bar material to form a channel shape. The new envelope frames were constructed using hollow square tubing which provided the same frame thickness dimension, but with reduced material weight. The configuration of these frames provided a 2X2 panel matrix in support of filtration gas flow direction and a 1X1 panel matrix in support of reverse cleaning gas flow direction. The installation of these envelopes in the filter casing was designed for air pulse cleaning in the same manner as used for all previous test configurations.

Another change performed for this series of tests was the ability to perform manually initiated "offline" cleaning of envelopes. All previous testing had used a control system which was activated by a high pressure drop set point, and cleaning was performed online as process air flow continued to flow through the filter. Offline cleaning was performed by using a damper to interrupt the process air flow during the time when the envelope was subjected to the pulse air cleaning.

Discussion of Test Results

Test 121 was an initial test to determine the pressure drop characteristic of the newly installed 10 to 12 micron porosity filter media. A pressure drop of approximately 0.2 IWG was obtained for an air flow of 500 ACFM corresponding to a filtration velocity of 10 FPM, as illustrated by Figure 2B-42. This value compares to a value of 0.1 IWG at 500 ACFM which was determined for the composite of Bekipore filter media previously tested. However, the newly installed Fluid Dynamics filter media indicated significantly increased porosity relative to the original Fluid Dynamics 1 micron porosity filter media which had a pressure drop characteristic of 3.4 IWG at 500 ACFM.

Although this newly installed filter media had significantly reduced porosity relative to the original Fluid Dynamics filter media, it also included a more robust internal matrix to support the filter fibers, in order to avoid failure of the filter media in flexing as had occurred during testing of the original filter media.

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Several preliminary tests were performed to investigate variation of operating conditions; filter air flow, air pulse pressure, and use of online and offline cleaning. The results of these tests were inconclusive and are not included in this report. However, cleanability of the filters was not effective and blinding of the filter media was suspected. Test 125 was a determination of residual filter pressure drop after completion of the preliminary tests. A pressure drop of 0.7 IWG at 500 ACFM, as illustrated by Figure 2B-43, is indicative of residual blinding relative to a new filter media pressure drop of 0.2 IWG.

Modification of Envelope Frames

Tests 126 through 135 were performed using a modification of one envelope frame located at position "D". The envelope frame at this location was identical to all other envelope frames, except that one edge of the frame, the bottom horizontal member, was converted to be the source of pulse cleaning air in order to replace the manifold source as used for the other three envelopes. The reinstallation of this envelope included installation of new filter media, which was the other new Fluid Dynamics 5 to 6 micron porosity filter media. The other three envelopes retained intensely cleaned previously installed 10 to 12 micron porosity filter media. Much of the test operation which followed included a comparison of conventional online cleaning to offline cleaning of the modified envelope.

Discussion of Test Results

Initial Test 126 was a determination of the pressure drop characteristic of the modified composite filter media system. A pressure drop of 0.47 IWG, as illustrated by Figure 2B-44, was less than the 0.7 IWG residual pressure drop of the 10 to 12 micron porosity filter media, and greater than the 0.2 IWG pressure drop of the new 10 to 12 micron porosity filter media.

Figure 2B-3 is a tabulation which summarizes the operating conditions and test results of Tests 127 through 135.

Test 127 was performed at 400 ACFM air flow, 8.0 FPM filtration velocity. This test used a test particulate consisting of a 5:0.2 ratio of 52 micron MMD Alumina powder and 3.7 micron MMD Silica powder, similar to the test particulate used for many previous tests. Pulse air pressure ranged from an initial 40 PSIG to a final 70 PSIG. Most test operations were performed by conventional online cleaning of the three conventional envelopes and offline cleaning of the modified envelope cleaning system configuration. Other test operating conditions were 0.6 second ontime air pulse duration and a 5.0 IWG high pressure drop set point cleaning initiation.

The results of Test 127 did not indicate any benefit of improving cleandown pressure drop from either the increase of air pulse pressure or use of offline cleaning. Cleandown pressure drop was concluded to be unsatisfactory at these operating conditions.

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Test operating conditions for Test 128 were similar to Test 127. Pulse air pressure for the three conventional envelopes was 40 PSIG. Pulse air pressure for the modified envelope was started at 20 PSIG and increased in steps to 40 PSIG.

Test results were again unsatisfactory. However, when operating at the greater air pressure, offline cleaning did produce lower cleandown pressure drop than did conventional online cleaning. It may be concluded that the offline cleaning of the one offline envelope was the only effective cleaning which occurred. It is possible that the offline cleaning event may have caused some cleaning of the conventional envelopes which were also subjected to a state of offline operation from the process air flow.

Test 129 was conducted similar to Test 128, except that the high pressure drop set point was increased to 10 IWG. Initial operation with 30 PSIG pulse air pressure used for both online cleaning of the three conventional envelopes and offline cleaning of the modified cleaning envelope produced essentially nil cleaning effectiveness, and, consequently, very frequent cleaning cycles were required.

Pulse air pressure was increased in steps until a pressure of 50 PSIG produced significantly improved cleaning. As was the case demonstrated by Test 128, offline cleaning of the modified envelope resulted in superior cleaning to an approximate 7.0 IWG cleandown pressure drop, while online cleaning of the conventional envelopes resulted in cleandown to only approximately 9.0 IWG. However, this phenomenon can again be explained by the offline cleaning event being effective for all envelopes.

Test 130 was conducted at a 500 ACFM, 10.0 FPM air flow operating condition and a 10.0 IWG high pressure drop set point. Other different operating conditions for this test were the use of only Sorbent/Precoat test particulate without including any simulated exhaust particulate, and the use of Neutralite precoat of the filter media at the beginning of the test.

Initial operation with 40 PSIG pulse air pressure for the modified envelope did not achieve effective cleaning. When pressure was increased to 70 PSIG, the result was an equilibrium cleandown pressure drop of approximately 8 IWG effective cleaning for both the offline cleaned envelope and the online cleaned envelope.

Test 131 was also conducted at conditions of an air flow of 500 ACFM, 10.0 FPM, a 10.0 IWG high pressure drop set point, use of Sorbent/Precoat only test particulate, and use of Neutralite precoat installed on the filter media at the start of the test. All test operations were at 80 PSIG pulse air pressure for both the offline cleaned modified envelope and the online cleaned conventional envelopes.

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Test results indicated a stable cleandown pressure drop of approximately 6.0 IWG for both the offline cleaned modified envelope and the online cleaned conventional envelopes.

Test 134 represented an attempt to sustain equilibrium pressure drop operation at a significantly reduced pressure drop than the previously investigated high pressure drop set points of 5.0 and 10.0 IWG. For this test, the high pressure drop set point was reduced to 3.2 IWG. Test operation air flow was reduced to 400 ACFM, 8.0 FPM for this optimistic operating condition. Other test operating conditions of Sorbent/Precoat only test particulate and the use of Neutralite filter media precoat were identical to operating conditions for previous successful tests.

All testing was performed with 80 PSIG pulse air pressure for both the modified and conventional envelopes. Cleaning of the modified envelope was performed with both manual offline cleaning and automatic online cleaning, when operating at 0.6 second ontime pulse duration and 80 PSIG pulse air pressure for both the modified and conventional envelopes. The test results did not indicate any significant difference between offline and online cleaning of the modified envelope, resulting in an equilibrium filter pressure drop of approximately 2.5 IWG.

After approximately 163 minutes of equilibrium 2.5 IWG cleandown pressure drop operation, air pulse ontime was increased from 0.6 seconds to 1.2 seconds. This change resulted in an improvement of cleandown pressure drop to approximately 1.8 IWG.

Test 135 was similar to Test 134, except that the high pressure drop set point was 4.3 IWG and all cleaning was performed at 0.6 seconds ontime. Essentially all cleaning of the modified envelope was performed as offline cleaning. The results of this test did not indicate any discernible difference between offline and online cleaning effectiveness, which ranged between 3.1 IWG and 4.1 IWG cleandown pressure drop.

Conclusions of Operation by Offline Cleaning of Modified Envelope Air Pulse Delivery Design

A comparison of the test results of the use of Fluid Dynamics 10 to 12 micron porosity and 5 to 6 micron porosity filter media installed on conventional online cleaned envelopes and a modified offline cleaned envelope, to the test results of previously tested Bekipore 5 micron porosity and 12 micron porosity filter media installed on conventionally online cleaned envelopes, did not make a decisive case of merit for the use of integral envelope frame pulse air delivery or use of offline cleaning embellishments. Although some tests did indicate that superior cleandown pressure drop was obtained by the use of offline cleaning, the composite effect upon the entire filter was not significant and did not justify the complication of including this embellishment in the Envelope Filter design.

**DOE/BETS TOPICAL REPORT
CHAPTER 2B**

It was also determined that more favorable pressure drop operation could be obtained by the use of filter media which did not include an excessive internal matrix to support filter fibers. Filter media vendors were requested to supply a more favorable filter media of this nature for further test evaluation by the laboratory cold flow Envelope Filter test facility.

A P P E N D I X 2B

DRAWING LIST

(APPENDIX 2B)

DRAWING NUMBER

DRAWING SUBJECT

S9513/FA800

COLD FLOW ENVEL. FLTR. ASSEMBLY, TOP ENTRY

FA801

COLD FLOW ENVEL. FLTR. COLLECTOR DETAILS

FA802

COLD FLOW ENVEL. FLTR. COLLECTOR DETAILS

FA803

COLD FLOW ENVEL. FLTR. HOPPER DETAILS

FA804

COLD FLOW ENVEL. FLTR. COLLECTOR AIR PIPING

FA805

**COLD FLOW ENVEL. FLTR. COLLECTOR DETAILS
(ENVEL.)**

FA806

COLD FLOW ENVEL. FLTR. COLLECTOR TUBE SHEET

FA807

COLD FLOW ENVEL. FLTR. COLLECTOR AIR PIPING

FA810

COLD FLOW ENVEL. FLTR. ASSEMBLY, SIDE ENTRY

NOTE: ANY ATTACHING
DUCTWORK NOT SHOWN
MUST BE PROPERLY
SUPPORTED. EXTERNAL
LOADS ON INLET & OUTLET
DUCT SECTIONS ARE NOT
PERMISSIBLE

PERFORATED PLATE
DESIGN TO BE DETERMINED
BY GEESI TEST LAB

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR ENGINEERING				
PROJECT MANAGER APPROVAL				
APPROVAL DATE				
MICROFILMED				

1/10" 1/16" 1/8" 1/4" 3/8" 1/2" 5/8" 3/4" 1" 1 1/4" 1 1/2" 1 3/4" 2" 2 1/4" 2 1/2" 2 3/4" 3" 3 1/4" 3 1/2" 3 3/4" 4" 4 1/4" 4 1/2" 4 3/4" 5" 5 1/4" 5 1/2" 5 3/4" 6" 6 1/4" 6 1/2" 6 3/4" 7" 7 1/4" 7 1/2" 7 3/4" 8" 8 1/4" 8 1/2" 8 3/4" 9" 9 1/4" 9 1/2" 9 3/4" 10"

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<h1 style="text-align: center;">GE Environmental Systems</h1>			
<h2>ENVELOPE FILTER COLLECTOR DETAILS</h2>							
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		<p>AUTHORIZATION NO.</p> <p style="font-size: 2em; text-align: center;">S9513</p>		<p>DRAWING NUMBER</p> <p style="font-size: 2em; text-align: center;">FA-801</p>			
<p>SCALE-</p> <p style="font-size: 1.5em; text-align: center;">NONE</p>		<p>REVISION</p> <p style="font-size: 2em; text-align: center;">0</p>					

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REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
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CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR ENGINEERING				
PROJECT MANAGER APPROVAL				
APPROVAL DATE				
MICROFILMED				

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REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
1	DRAWN BY			
2	CHECKED BY			
3	REVIEWED FOR DESIGN			
4	REVIEWED FOR ENGINEERING			
5	PROJECT MANAGER APPROVAL			
6	APPROVAL DATE			
7	MICROFILMED			

1/10" 1/8" 1/4" 3/8" 1/2" 3/4" 1" 1 1/4" 1 1/2" 1 3/4" 2" 2 1/4" 2 1/2" 3" 3 1/4" 3 1/2" 4" 4 1/4" 4 1/2" 5" 5 1/4" 5 1/2" 6" 6 1/4" 6 1/2" 7" 7 1/4" 7 1/2" 8" 8 1/4" 8 1/2" 9" 9 1/4" 9 1/2" 10" 10 1/4" 10 1/2" 11" 11 1/4" 11 1/2" 12" 12 1/4" 12 1/2" 13" 13 1/4" 13 1/2" 14" 14 1/4" 14 1/2" 15" 15 1/4" 15 1/2" 16" 16 1/4" 16 1/2" 17" 17 1/4" 17 1/2" 18" 18 1/4" 18 1/2" 19" 19 1/4" 19 1/2" 20" 20 1/4" 20 1/2" 21" 21 1/4" 21 1/2" 22" 22 1/4" 22 1/2" 23" 23 1/4" 23 1/2" 24" 24 1/4" 24 1/2" 25" 25 1/4" 25 1/2" 26" 26 1/4" 26 1/2" 27" 27 1/4" 27 1/2" 28" 28 1/4" 28 1/2" 29" 29 1/4" 29 1/2" 30" 30 1/4" 30 1/2" 31" 31 1/4" 31 1/2" 32" 32 1/4" 32 1/2" 33" 33 1/4" 33 1/2" 34" 34 1/4" 34 1/2" 35" 35 1/4" 35 1/2" 36" 36 1/4" 36 1/2" 37" 37 1/4" 37 1/2" 38" 38 1/4" 38 1/2" 39" 39 1/4" 39 1/2" 40" 40 1/4" 40 1/2" 41" 41 1/4" 41 1/2" 42" 42 1/4" 42 1/2" 43" 43 1/4" 43 1/2" 44" 44 1/4" 44 1/2" 45" 45 1/4" 45 1/2" 46" 46 1/4" 46 1/2" 47" 47 1/4" 47 1/2" 48" 48 1/4" 48 1/2" 49" 49 1/4" 49 1/2" 50" 50 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NOTES:
1. FOR GENERAL NOTES SEE DRAWING D/FA-800.

DESCRIPTION	DESCRIPTION	DESCRIPTION

GE Environmental Systems		
ENVELOPE FILTER COLLECTOR HOPPER DETAILS		
<div style="border: 1px solid black; padding: 5px; text-align: center;">5</div>		
<small>NOTES</small> This is a representation of a proposed design of General Electric Environmental Systems, Inc. and is subject to change without notice. It is not to be used for construction or for any other purpose without the written approval of General Electric Environmental Systems, Inc.		ISSUED FOR CONSTRUCTION DATE
AUTHORIZATION NO. S9513	DRAWING NUMBER FA-803	REVISION 0
SCALE: NONE		

APR 21 1990 11:40 RD

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C

B

A

WELD AT 1 1/8" DIA. HOLE IN WALL AFTER ALL HOLES IN BLOW PIPE HAVE BEEN ALIGNED TRUE & VERTICAL OVER CENTERLINE OF OPENING IN TUBE SHEET

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR ENGINEERING				
PROJECT MANAGER APPROVAL				
APPROVAL DATE				
MICROFILMED				

1/0" 1/8" 1/4" 3/8" 1/2" 5/8" 3/4" 1" 1 1/4" 1 1/2" 1 3/4" 2" 2 1/4" 2 1/2" 3" 3 1/4" 3 1/2" 4" 4 1/4" 4 1/2" 5" 5 1/4" 5 1/2" 6" 6 1/4" 6 1/2" 7" 7 1/4" 7 1/2" 8" 8 1/4" 8 1/2" 9" 9 1/4" 9 1/2" 10"

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2 SECTION
804

NOTE: INDEX NOS. "31", "36", "37", "38", AND "40" ARE IDENTICAL TO SECTION "4". ALL WELDS, DETAILS AND DIMENSIONS NOT SHOWN ARE IDENTICAL TO SECTION "4".

4 SECTION
804

3/8"-16 UNC X 1 1/4" LG. HEX HD. BOLT W/ HEX NUT, FLATWASHER & LOCKWASHER BURR THREADS AT END OF BOLT AFTER ASSEMBLY

(34) 7/16" DIA. HOLES - TYP. TOP & BOTTOM FLANGE

3 SECTION
804

1 SECTION
804

NOTES

1. FOR GENERAL NOTES SEE DRAWING D/FA-800.
2. ALL MATERIAL TO BE 3/16" THK. ASTM A-36, UNLESS NOTED.

DESCRIPTION	DESCRIPTION	0	DESCRIPTION
		Draw	
		PLS (S-EL)	
		HT 8/30/90	
		Revised	

DRAWN
1/30/90

<p>GE Environmental Systems</p> <p>ENVELOPE FILTER COLLECTOR</p> <p>AIR PIPING PLENUM ASSEMBLY AND DETAILS</p>		
<p>ISSUED FOR CONSTRUCTION</p>		<p>DATE</p>
<p>AUTHORIZATION NO.</p> <p>S9513</p>	<p>DRAWING NUMBER</p> <p>FA-804</p>	<p>REVISION</p> <p>0</p>

SCALE - NONE

ISO 9001

REV 01 12/90 11/90

NOTES

1 FOR GENERAL NOTES SEE DRAWING D/FA-800.

GE Environmental Systems

ENVELOPE FILTER COLLECTOR DETAILS

ISSUED FOR CONSTRUCTION		DATE
AUTHORIZATION NO.	DRAWING NUMBER	REVISION
S9513	FA-805	0

	DESCRIPTION		DESCRIPTION	0 D/W EUB (3-22) HL 5/20/90 R. Kline	DESCRIPTION
					DRAWN 1/30/90

SCALE-- NONE

APR 21 1963 MF:RO

D

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REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR ENGINEERING				
PROJECT MANAGER APPROVAL				
APPROVAL DATE				
MICROFILMED				

1/10" A991/FA806

1/8"-1/4"

3/8"-3/4"

1. FOR GENERAL NOTES SEE DRAWING D/FA-800.

[illegible]

DRILLED HOLES TO BE FREE FROM BURRS
ON THE INSIDE & OUTSIDE OF PIPE.
REMOVE ALL LOOSE DRILL TURNINGS,
TAILINGS & CHIPS FROM INSIDE THE
PIPE. ALL HOLES MUST ALIGN VERTI-
CALLY WITH MAXIMUM ALLOWABLE
TOLERANCE AT $\pm 2^\circ$ ANGULAR ROTATION
OFF VERTICAL CENTERLINE.

TRUE
VERTICAL

3 SECTION

807

L 1 1/2 x 1 1/2 x 1/8 x 1 1/2 LG.

A DETAIL

807

3/4" SCH. 40 PIPE
X 2" LG. T.O.E.

31 AIR PIPE

3/4" SCH. 40 PIPE
X 4 1/4" LG. T.O.E.

32 AIR PIPE

3/4" SCH. 40 PIPE
X 5 1/4" LG. T.O.E.

33 AIR PIPE

3/4" STD. COUPLING
W/ 3/4" STD. PIPE
PLUG. CENTER ON
1" DIA. HOLE
IN PIPE

1/8" MAXIMUM ALLOWABLE SWEEP
EITHER SIDE OF CENTERLINE

2 VIEW

807

A

807

(4) 3/4" DIA.
HOLES

(3) 1/2" DIA.
HOLES

(4) 3/4" DIA.
HOLES

3

807

34 BLOW PIPE

(4) 3/4" DIA.
HOLES

(3) 1/2" DIA.
HOLES

3

807

35

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR ENGINEERING				
PROJECT MANAGER APPROVAL				
APPROVAL DATE				
MICROFILMED				

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REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR ENGINEERING				
PROJECT MANAGER APPROVAL				
APPROVAL DATE				
MICROFILMED				

1/0" 1/16" 1/8" 3/16" 1/4" 3/8" 1/2" 5/8" 3/4" 7/8" 1" 1 1/8" 1 1/4" 1 1/2" 1 3/4" 2" 2 1/4" 2 1/2" 2 3/4" 3" 3 1/4" 3 1/2" 3 3/4" 4" 4 1/4" 4 1/2" 4 3/4" 5" 5 1/4" 5 1/2" 5 3/4" 6" 6 1/4" 6 1/2" 6 3/4" 7" 7 1/4" 7 1/2" 7 3/4" 8" 8 1/4" 8 1/2" 8 3/4" 9" 9 1/4" 9 1/2" 9 3/4" 10"

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2 VIEW
810

1 SECTION
810

ANY ATTACHING
WORK NOT SHOWN
T BE PROPERLY
ORTED. EXTERNAL
DS ON INLET OR
T DUCT SECTIONS
OT PERMISSIBLE.

SIDE ELEVATION

NOTES:

1. FABRICATION TO BE IN ACCORDANCE WITH SPECIFICATION NUMBER A/SXX-9.
2. FOR WELDING SPECIFICATION, SEE SPECIFICATION NUMBER A/XX-003.
3. ALL MATERIAL TO BE: 16 GA. ASTM A-570, GRADE 36 UNLESS NOTED.
4. ALL PLATE MATERIAL TO BE ASTM A-36.
5. ALL STRUCTURAL MEMBERS TO BE ASTM A-36.
6. ALL PIPE TO BE ASTM A-120 UNLESS NOTED
7. ALL PIPE FITTINGS TO BE 150 LB. MALLEABLE IRON, ASTM A-197, SCREWED ANSI B16.3, UNLESS NOTED.
8. NO PAINT REQUIRED.
9. FOR LIST OF REFERENCE DRAWINGS AND QUANTITIES SEE BILL OF MATERIAL A/BFA-1

GE Environmental Systems

ENVELOPE FILTER COLLECTOR ASSEMBLY SIDE ENTRY

NOTES
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SCALE- NONE

ISSUED FOR CONSTRUCTION

DATE

AUTHORIZATION NO.

DRAWING NUMBER

REVISION

S9513

FA-810

0

DESCRIPTION

DESCRIPTION

0

DESCRIPTION

DRAWN

2/27/80

VZ-1

150 MM

APR 01 1980 11P 10

TABLE 28-1
SUMMARY OF PRELIMINARY ENVELOPE FILTER TEST OPERATING CONDITIONS AND TEST RESULTS
CHAPTER 28
FILE SC2BD1

TEST SERIES	001	001	001	001
TEST NUMBER	003	004	005	006
FILTER AIR FLOW, ACFM	500	400	526	435
FILTRATION VELOCITY, FPM	9.7	7.8	10.2	8.6
TEST PARTICULATE:				
TYPE	SILICA	SILICA	ALUMINA	ALUMINA
SIZE, MICRONS MMD	3.6	3.6	52	52
FILTER INLET, GRAINS/ACF	1	1	5	5
PULSE PRESSURE, PSIG:				
START	40	80	80	80
CHANGED TO	80			
PULSE ONTIME, SECONDS:				
START	.04	.04	.005	.005
CHANGED TO		.055		
PULSE OFF TIME, SECONDS (SEE NOTE*):				
START	12.5	12.5	28	28
CHANGED TO		27.2		
HIGH PRESSURE DROP SET, IWG	12	12	15	15
LOW PRESSURE DROP SET, IWG	10	10	10	10
F/F FILTER PRESSURE DROP:				
START	4.2	3	5.2	4.5
END	24.7	15.5	31	13
TEST DURATION, MINUTES	16	31	25	32
CONTINUOUS CLEANING	YES	YES	YES	YES
FILTER EFFLUENT EMISSIONS TESTED	NO	NO	YES	YES
GRAINS/ACF			.0164	.0189
COLLECTION EFFICIENCY, %			99.64	99.53
COMMENTS:			SUSPECT DUST LEAK AROUND FILTER MEDIA	

*NOTE:
DURING THESE TESTS THE PULSE AIR SUPPLY WAS LIMITED
AND REQUIRED LONG OFFTIME FOR PRESSURE RECOVERY.

* TABLE 28-1 *

TABLE 2B-2
SUMMARY OF TEST OPERATING CONDITIONS AND TEST RESULTS
FOR
COMPOSITE 5 MICRON STAINLESS STEEL FIBER AND 12 MICRON INCONEL FIBER BEKIPOR FILTER MEDIA
CHAPTER 2B
FILE SC2B02

TEST SERIES	002	002	002	002	002	002	002	002	002
TEST NUMBER	108	109	110	111	112	114	115	119	120
TEST DATE	9/20/90	9/21/90	10/3/90	10/4/90	10/5/90	10/8/90	10/9/90	10/15/90	10/19/90
AIR FLOW, ACFM	400	507	500	600	400	400 TO 600	300	400 TO 500	500
FILTRATION VELOCITY, FPM	8.36	10.14	10	12	8	8.0 TO 12.0	6	8 TO 10	10
PULSE PRESSURE, PSIG	40 TO 35	35 TO 50	45 TO 55	50 TO 60	10 TO 55	35 TO 55	20 TO 60	50 TO 60	50 TO 60
PULSE ONTIME, SECONDS	0.6 TO 1.1	.6	1.0 TO .064	1.0 TO 0.2	1.0 TO 0.6	.6	0.6 TO 0.1	0.6 TO 0.2	.2
PULSE OFFTIME, SECONDS	10	10	10	10	10	10	10	10	10
HIGH PRESSURE DROP SET POINT, ING	5	10	10	10	10	5	5	4.7	10
LOW PRESSURE DROP SET POINT, ING	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
TEST PARTICULATE, SP:EP	5:0.2	5:0.2	5:0.2	4.13:0.17	5:0.2	5:0.2	34MMD FLYASH	15.5MMD FLYASH	2.5:.2
TEST PARTICULATE CONCENTRATION, GRAINS/ACF	6.17	5.22	-	4.3	5.2	5.2	6.5	5.48	2.06
NEUTRALITE PRECOAT, GRAMS	292	NO	NO	NO	NO	292	NO	NO	NO
FILTER EFFLUENT, GRAINS/ACF	.0017	.0014	-	-	-	-	-	-	-
PARTICULATE COLLECTION EFFICIENCY, %	99.97	99.97	-	-	-	-	-	-	-
CLEANDOWN PRESSURE DROP, ING:									
MAXIMUM EFFECTIVE	0.8 TO 2.3	5.5 TO 8.0	6.5	7	6.5	3.5	2	3.5	8
MINIMUM EFFECTIVE			8.5	9	8	4.2	4.5	4.3	9

TABLE 2B-3
SUMMARY OF TEST OPERATING CONDITIONS AND TEST RESULTS
FOR
FLUID DYNAMICS 10-12 MICRON POROSITY AND 5-6 MICRON POROSITY FILTER MEDIA
CHAPTER 2B
FILE SC2B03

TEST SERIES	003	003	003	003	003	003	003
TEST NUMBER	127	128	129	130	131	134	135
TEST DATE	12/20/90	1/2/91	1/3/91	1/8/91	1/10/91	1/22/91	1/23/91
AIR FLOW, ACFM	400	400	400	400 TO 500	400 TO 500	400	400
FILTRATION VELOCITY, FPM	8	8	8	8.0 TO 10.0	10	8	8
PULSE PRESSURE, PSIG (MANIFOLD/FAME)	40 TO 70	40/20 TO 40/40	30/30 TO 50/50	40/40 TO 70/70	80	80	80
PULSE ONTIME, SECONDS	.6	.6	.6	.6	.6	0.6 TO 1.2	.6
PULSE OFFTIME, SECONDS	5	5	5	5	30	30	30
HIGH PRESSURE DROP SET POINT, INQ	5.2	5.2	10	10	10	3.2	4.3
LOW PRESSURE DROP SET POINT, INQ	NONE	NONE	NONE	NONE	NONE	NONE	NONE
TEST PARTICULATE SP:EP	5:0.2	5:0.2	5:0.2	5:0:0	5:0:0	5:0:0	5:0:0
TEST PARTICULATE CONCENTRATION, GRAINS/ACF	5.02	5.3	5.2	5.11	5.32	5.38	5.34
NEUTRALITE PRECOAT, GRAMS	NO	NO	NO	300	300	300	300
FILTER EFFLUENT, GRAINS/ACF	-	-	-	-	-	-	-
PARTICULATE COLLECTION EFFICIENCY, %	-	-	-	-	-	-	-
CLEANDOWN PRESSURE DROP, INQ:							
MAXIMUM EFFECTIVE	3.5 TO 5.8	3.9 TO 5.0	7 TO 9	7.5 TO 8.2	6	1.8	3.1 TO 4.1
MINIMUM EFFECTIVE	-	5	9.5 TO 10 0	8.2 TO 9.8		2.5	
CLEANING AUTOMATIC ONLINE	3	3	3	3	3	3	3
CLEANING MANUAL OFFLINE	1	1	1	1	1	1	1
ENVELOPE FRAME CONFIGURATION:	3010-12MICRON	SAME	SAME	SAME	SAME	SAME	SAME
	105-6MICRON	SAME	SAME	SAME	SAME	SAME	SAME
AIR PULSE DELIVERY:							
MANIFOLD	3	3	3	3	3	3	3
ENVELOPE FRAME	1	1	1	1	1	1	1

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/001 NONE FILTER MEDIA

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/002 FD SS FILTER MEDIA

—□— INLET DUCT
 —x— TUBESHEET
 —△— FLANGE/FLANGE

PRESSURE DROP, IN. WG.

ENVELOPE FILTER INLET AIR FLOW, ACFM

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/005 FD SS FILTER MEDIA

— EF F/F DP
— EF A/C

* FIGURE 2B-3 *

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/006 FD SS FILTER MEDIA

— EF F/F DP
— EF A/C

* FIGURE 2B-4 *

ENVELOPE FILTER TEST PLAN

TEST NUMBER	007	008	009	010	011
ACF	400	400	400	400	400
ON, m. sec	55	55	55	>55-80	55
OFF, sec	28	28	28	>28	28
PSIG	80	80	80	80	100
High Set, in. W.G.	15	20	12	15	15
Low Set, in. W.G.	10	15	7	10	10
Feed Silica, Grains/CF	1	1	1	1	1
Feed Alumina, Grains/CF	5	5	5	5	5
TEST NUMBER	012	013	014	015	016
ACF	400	400	450	500	300
ON, m. sec	>55-80	55	TBD	TBD	TBD
OFF, sec	>28	28	TBD	TBD	TBD
PSIG	60	80	TBD	TBD	TBD
High Set, in. W.G.	15	15	15	15	15
Low Set, in. W.G.	10	10	10	10	10
Feed Silica, Grains/CF	1	1	1	1	1
Feed Alumina, Grains/CF	5	10	5	5	5

LAST REVISION DATE 08/31/90

TEST DATE	06/07/99	06/10/99	06/19/99	06/13/99	06/14/99	06/20/99	06/22/99	06/23/99	06/27/99	06/29/99	06/30/99
TEST DATE	06/07/99	06/10/99	06/19/99	06/13/99	06/14/99	06/20/99	06/22/99	06/23/99	06/27/99	06/29/99	06/30/99

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/007 FDSS/421CF/8.34F/80P/55mS/28S/15I/10I/5:1
 EF F/F DP

— EF A/C

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/010 FDSS/391CF/7.73F/80P/100mS/35S/15I/10I/5:1
 EF F/F DP

— EF A/C

 * FIGURE 2B-8 *

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/011 FDSS/435CF/8.60F/100P/55mS/28S/15I/10I/5:1
 EF F/F DP

— EF A/C.

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/0011A FDSS/430CF/8.51F/100P/55mS/28S/15I/10I/5:1
 — EF F/F DP
 — EF A/C

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/016 FDSS/392CF/7.76F/100P/55mS/28S/12I/9.10I/5:1
 EF F/F DP

EF A/C

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/011B FDSS/414CF/8.19F/100P/55mS/10S/15I/11I/5:1
 EF F/F DP

— EF A/C

 * FIGURE 2B-12 *

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/008 FDSS/398CF/7.88F/100P/55mS/20I/15I/5:1
 — EF F/F DP
 — EF A/C

 * FIGURE 2B-13 *

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/009 FDSS/414CF/8.19F/100P/55mS/10S/20I/18I/5:1
 EF F/F DP — EF A/C.

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/012 FDSS/420CF/8.23F/(60--100P/55mS/10S/20I/18I/5:1) EF F/F DP

— EF A/C.

* FIGURE 2B-15 *

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/101/435CF/8.61/100P/55mS/10S/20I/18I/5:0
 EF F/F DP

— EF A/C

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/102/FDSS/429CF/8.49F/100P/55mS/10S/20I/18I/5:1

* FIGURE 28-17 *

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/103 FDSS/436CF/8.62F/100P/100mS/10S/20I/18I/5:1
 EF F/F DP

--- EF A/C

 * FIGURE 2B-18 *

DOE/GETS CWM DIESEL FUEL PROGRAM

S:1

TEST 001/104 FDSS/396CF/7.84F/(90 TO)100P/55ms/10S/20I/18I

— EF A/C

— EF F/DP

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 001/106 FDSS/322CF/6.37F/100P/55ms/10S/121/101/5:1

— EF F/F DP
— EF A/C

DESIGN TO BE DETERMINED
 BY GEESI TEST LAB
 3377

IMBRILED (6) 1/2" LABEL VAMES PERPENDING TO AND
 (EQUALLY SPACED) FROM DIAGONAL
 EXISTING PERP. PLATE (BLANK)

5'-1 1/2"

CENTERLINE TO FACE OF FLANGE

CENTERLINE TO FACE OF FLANGE

VELOCITY TRAVERSES
 TYPICAL, APPROX
 16 ENVELOPES
 13x5 DATA MATRIX

VELOCITY TRAVERSES,
 TYPICAL, BETWEEN
 ENVELOPES
 13x7 DATA MATRIX

NOTES:
 1. SHOWN
 2. Y
 3. INTERNAL
 4. & OUTLET
 5. ARE NOT

AIMM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIMM STANDARDS
BY APPLIED IMAGE, INC.

3 of 7

TEST #2 @ ~ TOP OF INDUSTRY (GAP Flow Approach)

Test Q ~ 700 AFM

$$T_{Est \ V} = 700 \div 5.983 \text{ K}^2 = 117.0 \cdot \text{K}$$

AUG. TRAV₃₂₈₃ DATA = 204.23 RPM > 117.0 RPM

Test #2 @ ~ Bottom of Envelopes

Test Q ~ 700 ACFM

$$\text{Test T} = \left(\frac{0.22}{1.00} \right) \times 700 \div \left(5.303 \times \left(\frac{22}{22} \right) \right) = +17.40 \text{ FPM}$$

Avg. TRAVERSE T DATA = +58.41 FPM 7 +17.40 FPM

Matrix Values = f(T)

* ADJUSTMENT OF TOTAL TEST AIR FLOW TO AIR FLOW WHICH HAD NOT YET ENTERED ENVELOPES.

** ADJUSTMENT TO AREA BETWEEN ENVELOPES.

Test #4 - At Top of $\Sigma = \text{Lapse}(\text{Garfay to A. G. M.})$

Test Q ~ 700 μ m

$$T_{\text{set } T} = 700 + (5.983 \times 12/22) = 214.50 \text{ mm}$$

AUG TRANS: $\bar{V}$ DATA = 147.50 $\frac{\text{mm}}{\text{min}}$ 214.50 $\frac{\text{mm}}{\text{min}}$

$$\text{Matrix Law} = f(\bar{v})$$

Test #4 CONFIGURATION — T.V. INSTALLED T. OPTIMIZ
GAS FLOW DISTRIBUTION

*** FIGURE 25-25 ***

44

Test #2 - Bottom in [] = 0.00

Test Q ~ 700 ACUM

$$Test \bar{V} = \left(\frac{0.22}{1.80} \right) \times 700 = \left(5.983 \times \left(\frac{22}{22} \right) \right) = +17.43 \text{ mm}$$

Avg. ~~Raw~~ $\bar{V}$ DATA = +12.20 mm > +17.42 mm

MATRIX LAW = -f(V)

Test #2 CONFIGURATION - T.V. IS STALLED TO OPTIMIZE CAFEW DISTRIBUTION

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 002/107 BEKIPOR 2-5 μ M SS AND 2-12 μ M INCONEL

- INLET DUCT
- x— TUBESHEET
- ▽— FLANGE/FLANGE

ENVELOPE FILTER INLET AIR FLOW. ACFM.

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION NEUTRALINE (HYDROLYZABLE SILICATE) (1255 RUN #2) (GETS FEWS PRECIPITATE)

DATE 2/9/90

BY M. G. Donald

Density 2.30 g/cc LIQUID SEDIMENT 411 Density 0.753 g/cc Viscosity 1.415 cp

Preparation 0.6090 g < 104 µm SAMPLE DISPERSED IN 25 ml FLUID

TEMPERATURE 30 °C

0.00% > 104 µm PROGRAM STARTED AT 0.0%

RATE 926 START DIA. 100 µm

EQUIVALENT SPHERICAL DIAMETER, µm

m micromeritics

* FIGURE 28-28 *

ENVELOPE FILTER TEST #108 BEKIPORE FILTER MEDIA, 400 acfm

DOE/GETS CWM DIESEL FUEL PROGRAM

TEST 002/109 BEK. 5&12uM/507CF/10.0F/50P/0.6S/10S/10I/10I/
 EF F/F DP

— EF A/C

 * FIGURE 2B-30 *

ENVELOPE FILTER TEST # 110 BEKIPORE FILTER MEDIA, 500 acfm

ENVELOPE FILTER TEST # 111

BEKIPORE MEDIA, 600 acfm

 * FIGURE 2B-32 *

ENV.FIL.TEST #112/PULSE PRES. VS ON TIME BEKIPORE MEDIA/5.0 & 12.0 micron 400 acfm

ENV.FIL.TEST #114/NEUTRALITE PRE-COAT 400 BEKIPORE FILTER MEDIA / 5.0 & 12.0 micron

* FIGURE 2B-34 *

ENV.FIL.TEST #115/APS FLYASH BEKIPORE FILTER MEDIA / 5.0 & 12.0 micron

PARTICLE SIZE DISTRIBUTION

DATE 10-11-90

BY M. R. Arnold

TEMPERATURE 29 °C

RATE 737 START DIA. 100 1111

ENVIRONMENTAL FILM
HOLLYWOOD RECORDING
TEST #115 (10-9-90)
Density 1.38 cp

Viscosity 1.38 cp

Preparation 0.7192g $\times$ 104 μ m - Sample Dispersed in = 25 ml LIQUID

PROGRAM STARTED AT 10.070

EQUIVALENT SPHERICAL DIAMETER, μ (III)

m, micromeritics.
instrument corporation

* FIGURE 2B-36 *

ENV.FIL.TEST #119 / CLEANABILITY TEST BEKIPORE MEDIA/CHINA TEST DUST 15.5 micron

* FIGURE 2B-37 *

PARTICLE SIZE DISTRIBUTION

DATE 10-11-90

SAMPLE IDENTIFICATION DOE/CWS/ENVEL.FIL. EXPECTED FIELD MATERIAL (CHINA LSP-COML-ASU)

Density 2.2383 g/cc LIQUID SEDIMENTATION Density 0.752 g/cc Viscosity 1.36 cp

BY M. L. Arnold

Preparation 0.7080 g < 104 μ m SAMPLE DISPERSION IN 25 ml LIQUID

TEMPERATURE 21 °C

7.11 % > 104 μ m

RATE 912 START DIA. 100 μ m

EQUIVALENT SPHERICAL DIAMETER, μ m

M, micromeritics

* FIGURE 2B-38 *

ENVELOPE FILTER w/ SUPER-BEINGAL

FILTER MEDIA

SUBJECT: SEDIMENT ANALYSIS OF

ENVELOPE "D" MIAL RECOVERY

TEST # 119 - CHINA L.P. (FLUSH) TEST

PERFORMED PLATE
DESIGN TO BE DETERMINED
BY GEESI TEST LAB

5'-1 1/2"

CENTERLINE TO FACE OF FLANGE

2'-11 1/2"

CENTERLINE TO FACE OF FLANGE

FLANGE
"A"

TY:

SUPPORT LI
TYP.

SUPPORT LUG
TYP. (2) PLACES
NEAR SIDE &
FAR SIDE

2'-10 3/4"

3'-0" ERLINE TO FACE OF FLANGE

6" SQUARE
VIEW PORT
TYP. (2) PLACES
NEAR SIDE &
FAR SIDE

ENV.FIL.TEST #120 / CLEANABILITY TEST BEKIPORE MEDIA/2.5 Al2O3 TO 0.2 SILICA/acf

ENV.FIL.TEST #118 / RESIDUAL D.P. Vs acfm BEKIPORE FIL.MED./5.0 & 12.0 MICRON ELEMENT

ENVELOPE FILTER TEST 121 DP VS. ACFM
F.D. (4) 10-12 MICRONS

* FIGURE 2B-42 *

ENV. FILTER TEST 125 RESIDUAL DP VS. ACFM
F.D. (4) 10-12 MICRON

* FIGURE 2B-43 *

ENVELOPE FILTER TEST 126 DP VS. ACFM

F.D. (3) 10-12 MICRON, (1) 5-6 MICRON

ENV.FIL.TEST #127/400 ACFM(5.2 Al2O3/SILICA F.D.(3)10-12 MICRON,(1)5-6 MICRON ENVELOPE

* FIGURE 2B-45 *

ENV.FIL.TEST #128/400 ACFM(5.2 AL203/SILICA
F.D.(3)10-12 MICRON,(1)5-6 MICRON ENVELOPE (WITH ENV 1 OFF
LINE)

* FIGURE 2B-46 *

ENV.FIL.TEST #129/400 ACFM(5.2 Al2O3/SILICA F.D.(3)10-12 MICRON,(1)5-6 MICRON ENVELOPE(ENV 1 OFF LINE)

ENV. FIL. TEST #130/AI2O3, 5.0 GRAINS/CU. FT.

F.D.(3)10-12 MICRON, (1)5-6 MICRON ENVELOPE

ENV.FIL.TEST #131/400ACFM(5.0 gr.A1203) F.D.(3)10-12,(1)5-6 MICRON,(1)ENV.OFF

ENVELOPE FILTER TEST #134

VOL.=400 ACFM/A1203 -5.0 gr./ACFM

 * FIGURE 2B-50 *

ENVELOPE FILTER TEST #135

VOL.=400 ACFM/AI203 -5.0 gr./ACFM

TAB 4

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CHAPTER 2C

CHAPTER 2C

Commensurate with Task 2, Emissions Applied R&D

Task 2.2.1 & 2.2.2

Laboratory cold flow testing of various candidate Emissions Control Concepts

Envelope type Barrier Filter. Microsystem/Patch Test Facility

Introduction

Following the completion of testing of the 500 ACFM, 10.0 FPM Envelope Filter Test 135, it was determined that there was potential improvement of filter pressure drop operation, depending upon the filter media installed and the test operating conditions. In consideration of limited timely availability of required size alternative filter media for installation on the filter envelopes, it was decided to perform testing of small panels of filter media, 6 in. X 12 in. in size, which were commonly available from filter media vendors.

A test facility was constructed for cold flow laboratory testing as described by Figure 2C-1, enclosed in Appendix 2C. This facility was designed to replicate operation of the 500 ACFM Envelope Filter facility operating with top gas flow entry and with side gas flow exit, at a size which was only 1/100 of the larger facility. The facility was also constructed to permit offline reverse air pulse cleaning. Although the test results of use of various filter media samples were not absolute indications of the cleanability of larger size envelope dimensions, it was perceived to provide comparative test results for different filter media characteristics.

Based upon the results of the previously conducted tests of the 500 ACFM cold flow Envelope Filter, targeted optimum operating conditions of 10.0 FPM air flow, 60 PSIG pulse air pressure, and 0.6 sec. pulse ontime, as well as use of offline cleaning, were used for most of the tests performed with the Microsystem/Patch test facility.

Significant innovative investigation undertaken during the test program was use of Electrostatic Enhancement operation. The objective of this procedure was to create a more porous particulate filter cake layer deposited on the filter media. An achievement of this objective was perceived to reduce filter pressure drop while retaining an optimum amount of sorbent deposited on the filter media for reaction with exhaust gas constituents.

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Different methods of Electrostatic Enhancement operation were performed, and test results were compared to similar test conditions without Electrostatic Enhancement operation. The evaluation of test results consisted of the equilibrium cleandown pressure drop and the operating time interval between cleaning events. For the case of the latter criterion, longer time between cleaning events was indicative of more particulate filter cake layer deposited on the filter media. However, the evaluation was very dependent upon control of the particulate feed rate test condition.

Almost all testing was performed using offline cleaning. Each cleaning event included two air pulse cleanings. For tests which were performed using Electrostatic Enhancement, the high voltage field system was turned off during cleaning, beginning with Test 007. For tests prior to Test 007 (Tests 004 and 005), the high voltage field remained connected during cleaning.

Discussion of Test Results

Table 2C-1, enclosed in Appendix 2C, is a detailed summary of test operating conditions and observations of test results. Also, included in Appendix 2C are graph depictions of the results of each test performed. These graph depictions illustrate filter media pressure drop vs. test time, for all cleaning events of the test duration.

Tests 001 through 008 all utilized Bekipore PR169 filter media consisting of Inconel fibers producing 12 micron porosity on the filter inlet side and 22 micron porosity on the filter outlet side. All tests also utilized test particulate operation with a mixture of alumina powder (52 micron MMD) and coal flyash (15 micron MMD) in a mixture ratio of 5:0.4 to simulate sorbent/precoat:CWS fuel ash. Tests 001 through 003 did not include use of Electrostatic Enhancement operation.

Test 001 was a shakedown test as shown by an out-of-control particulate feed rate of 19.9 grains/ACF, relative to a planned test operating condition of 5 grains/ACF.

Tests 002 and 003 were conducted at essentially identical operating conditions and both tests represented improved achievement of the desired 5 grains/ACF particulate feed rate. Both tests also achieved excellent cleandown pressure drop < 1 IWG and average time intervals of 17 to 22 minutes between cleaning events as a result of the excellent cleandown.

Test 004 represents an initial use of Electrostatic Enhancement operation, which was performed by operation of a "precharger" device installed in the filter facility inlet duct. The device configuration consisted of wire emitters charged to -11.0 KV. The electrical circuit was completed by a panel at the duct wall which was at ground potential. The filter media also acted at ground potential.

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The theory of Electrostatic Enhancement operation was that the corona flow of electrons between the electrodes would impart a like electrical charge to particulate passing through the charging field. When the particles were deposited on the filter media, being of like charge, particles would repel and form a more porous layer.

The results of Test 004 imply successful achievement of the objective. Cleandown pressure drop was again at a desirable low value. Time between cleaning events increased significantly to 48 minutes, relative to previous test results. However, the entire credit for this improvement cannot be attributed to Electrostatic Enhancement operation, as the test particulate feed rate decreased to 3.1 grains/ACF. However, the improvement of the cycle time appeared to exceed the effect of the feed rate alone.

Test 005 was virtually a repeat of Test 004, except that the particulate feed rate was increased to closer to the desired 5 grains/ACF. Cleandown pressure drop duplicated Test 004 test results, and cycle time decreased commensurate with the increased feed rate. Also, there was again an apparent benefit demonstrated by the use of Electrostatic Enhancement operation.

For Test 006, an improved particulate feed rate system was used to improve control of this critical test operating condition. However, this test, performed without the use of Electrostatic Enhancement operation, resulted in an excessive particulate feed rate operating condition and, consequently, a much reduced cycle time test result relative to the results of Tests 002 and 003. The relationship of the particulate feed rate to the cycle time test result was indeterminate.

Another noteworthy aspect of Test 006 results was failure to achieve equilibrium cleandown pressure drop. As shown by depiction of test results, Figure 2C-7, initial cleandown pressure drop was 0.2 IWG, commensurate with previous test results. However, cleandown became less effective as the test progressed, and a value as high as 1.9 IWG was experienced before the end of the test.

Test 007 again employed Electrostatic Enhancement operation performed by the "precharger" located in the filter inlet duct, and again particulate feed rate was excessive. Test results, relative to cleandown pressure drop, were similar to the results of previous Test 006. Also, cleandown pressure drop increased as the test progressed. By the end of the test, cleandown appeared to have reached an equilibrium operating condition of 1.5 IWG.

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The initial portion of Test 007 and through the 18th cleaning event was performed with the high voltage field kept in operation during cleaning. From the 19th cleaning event through the end of the test, the high voltage was disconnected during cleaning. However, as illustrated by Figure 2C-8, there did not appear to be any significant benefit realized by the disconnected high voltage cleaning.

Test 008 was a virtual duplication of previous Test 007 in regard to operating conditions, including excessive test particulate feed rate. Test results were also similar to Test 007 in regard to cleandown pressure drop, as well as in regard to cleaning cycle time interval.

For Tests 009 through 012, test particulate was copper oxide coated alumina which had been consumed and recovered from single cylinder CWS fuel diesel engine slipstream test operation, including actual CWS fuel ash. This new test particulate had a particle size distribution MMD of 38 microns, which was finer than the test particulate used for previous Tests 001 through 008. It was of interest to explore actual use of this planned sorbent/precoat particulate, in consideration of the particle charging phenomenon which was being investigated.

Test 009 was conducted at the desired test particulate feed rate, but without the use of Electrostatic Enhancement operation. Test results of cleandown pressure drop and average cleaning cycle time interval were inferior to the results of Tests 002 and 003, which were conducted at very similar operating conditions. Also, test results were very similar to the results of Test 006, although Test 006 was conducted at a greater test particulate feed rate. Test 009 also evidenced a cleandown pressure drop characteristic which deteriorated as the test progressed, but appeared to reach an equilibrium 1.5 IWG by the end of the test.

Test 011 was a virtual duplication of Test 009 operating conditions and test results, except the cleandown pressure drop characteristic did not appear to have reached an equilibrium value at the end of the test.

The apparent inferior results of Tests 009 and 011, relative to referenced previous test results, could be attributed to the finer test particulate used. Another possible explanation is a gradual deterioration of the cleanability of the filter media as additional testing was performed.

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Test 010 was conducted using Electrostatic Enhancement operation with other operating conditions essentially the same as Tests 009 and 011. Cleandown pressure drop test results of Test 010 were very similar to the results of Tests 009 and 011. However, the results of Test 010, in regard to average time interval between cleaning events, was superior to the results of Tests 009 and 011. As illustrated by Figure 2C-12, cycle time did appear to be decreasing as the test progressed and cleandown pressure drop increased. This same characteristic was also evident for both Tests 009 and 011.

For Test 012, a different procedure was used for Electrostatic Enhancement operation. Starting with this test, the negative high voltage was applied to the filter media as well as to the emitters located in the filter inlet duct, relative to the ground potential of the wall panel electrode also located in the filter inlet duct. The purpose of this different procedure was to investigate a potential improvement of filter cake porosity. The theory for the procedure was that if the filter media was at the same charge potential as the particulate particles, the particles would tend to be repelled by the filter media as they were drawn toward the filter media by the filtration process. The net effect of repulsion between particles as well as between the particles and the filter media would, in theory, produce the most porous filter cake.

The test particulate feed rate operating condition for Test 012 was virtually identical to the operating condition for Tests 009, 010, and 011. Test 012 did produce cleandown pressure drop test results which were similar to the other test results. However, the time interval between cleaning events was significantly longer than the results of tests without the use of Electrostatic Enhancement, or the results of the test which used Electrostatic Enhancement only in the filter inlet duct "precharger".

For Tests 013, 014, and 015, test particulate was again with the coarser alumina and coal flyash mixture which was used as the test particulate for Tests 001 through 008. Cleandown pressure drop and time interval between cleaning events test results of Test 013 were similar to the results of Tests 007 and 008 which used the same test particulate as well as the same degree of excessive particulate feed rate. However, Test 013 also had the advantage of operation with the perceived superior dual high voltage charging procedure, relative to only the filter inlet duct "precharger" which was employed for Tests 007 and 008. It is not understood why Test 013 did not produce more favorable test results than the earlier tests.

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Beginning with Test 014 through Test 016, the filter media installed in the filter facility was changed to Fluid Dynamics E875, comprised of stainless steel fibers with a porosity rating of 20 microns. This filter media provided greater porosity than the 12/22 micron porosity filter media installed for Tests 001 through 013.

Test 014 was conducted without use of Electrostatic Enhancement operation and at an excessive test particulate feed rate. These operating conditions are comparable to the test operating conditions for Test 006, except for the different filter media. The results of Test 014 appear to be inferior to the results of Test 006 in regard to cleandown pressure drop as well as time interval between cleaning events. These differences may be attributed to the greater porosity filter media used for Test 014.

In Test 015, dual location Electrostatic Enhancement operation was again performed. Test particulate feed rate was again out-of-control and averaged more than 3 times the desired feed rate. Because of the test particulate feed rate operating condition, test results are not easily comparable to other test results. However, a comparison to Test 014, which was also conducted at an excessive particulate feed rate, but without Electrostatic Enhancement operation, does provide an opportunity to evaluate the benefit of Electrostatic Enhancement operation. The comparison of cleandown pressure drop and time interval between cleaning events indicates quite similar test results for the two tests. This would indicate that there was no benefit to operation using Electrostatic Enhancement for Test 015. However, some benefit may have been masked by the greater test particulate feed rate used for Test 015.

An additional test diagnostic determined starting with Test 015 was a that of the particulate escape through the tested filter media. The quantification of the escape particulate was performed by an absolute filter located downstream of the test filter media. Particulate escape was quantified in terms of the absolute particulate concentration, and as the collection efficiency of only the finer ash constituent in the test particulate. The results of Test 015 indicate virtually nil particulate escape through the test filter media. This fact proves the particulate integrity of the filter media and of the installation of the filter media in the test facility.

From Test 016 through Test 026, test particulate was again more representative of true operation, in regard to the effect of Electrostatic Enhancement operation on particulate charging. This test particulate consisted of 58 micron MMD alumina coated with copper sulfate, and was then mixed with 15 micron MMD coal flyash in a mixture ratio of 5:0.4.

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Test 016, which was conducted without use of Electrostatic Enhancement operation and at an excessive particulate feed rate, can be compared to Test 014. Cleandown pressure drop obtained in Test 016 was comparable to the results of Test 014, but the time interval between cleaning events obtained in Test 016 was significantly improved from the results obtained in Test 014. The reason for this apparent improved operation was not understood. The cycle time interval between cleaning events results obtained by Test 016 were, in fact, superior to results obtained by many tests performed using Electrostatic Enhancement operation.

New filter media was installed in the filter test facility for Tests 017 and 018. This new filter media was Fluid Dynamics E876 with a porosity rating of 30 microns, which was the most porous filter media tested during the testing program.

Test 017 was conducted without use of Electrostatic Enhancement operation, and at a low test particulate feed rate operating condition. Test results obtained were rather poor in comparison to Tests 002 and 003 which were performed at comparable operating conditions, but used less porous 12/22 micron porosity filter media. Another comparison to Test 014 showed similar results, although Test 014 was conducted using less porous 20 micron porosity filter media. Based upon these comparisons, there could be speculation that coarser porosity filter media produced less favorable filter media cleanability.

Test 018 was conducted with dual Electrostatic Enhancement operation and at an excessive test particulate feed rate. In comparison to Test 017, conducted without Electrostatic Enhancement operation, Test 018 produced similar cleandown pressure drop test results. Test 018 also produced much better average time interval between cleaning events, although the higher particulate feed rate was a disadvantage to test operation. This comparison indicated that there was merit to the use of Electrostatic Enhancement Operation.

Tests 019 through 026 were performed using new Fluid Dynamics E874 5/6 micron porosity rating filter media installed in the filter facility. All of these tests were also performed using similar test particulate operating conditions.

Test 019, which was conducted without use of Electrostatic Enhancement operation and at an excessive particulate feed rate, obtained cleandown pressure drop test results inferior to both Tests 014 and 016, which were conducted at comparable test operating conditions, but with the use of 20 micron porosity filter media. When compared to Test 006 which used 12/22 micron filter media, the results of Test 019 were again inferior. However, when compared to all of these same tests on the basis of cleaning event time interval, the results of Test 019 appear to be more favorable.

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Tests 020 and 022 were both conducted using dual Electrostatic Enhancement operation. Both tests obtained poor cleandown pressure drop test results relative to previous tests performed using more porous filter media. Test 020 produced a better average time interval between cleaning events than Test 022, by virtue of a lower test particulate feed rate for Test 020. However, the average time interval for Test 022 was similar to the results of Test 019 which did not employ Electrostatic Enhancement operation. In regard to cleaning event time interval, Test 022 results were similar to Test 018 which used 30 micron porosity filter media. However, the cleaning event time interval of Test 022 was the same as the test results of Test 019 which did not use Electrostatic Enhancement operation.

Test 023 was performed without use of Electrostatic Enhancement operation. The results of Test 023, when compared to similar test operating conditions in Test 019, were indicated as inferior.

Test 024 was also conducted without Electrostatic Enhancement operation. This test can be compared to Test 023 which was conducted at similar test operating conditions. Each of these tests produced similar test results.

Tests 025 and 026 were conducted with Electrostatic Enhancement operation and at similar test operating conditions (initial phase of Test 026). Test results of Test 025 were similar to previous Test 022, which was performed at similar test operating conditions with the same filter media. The results of Test 026 were inferior to any previous test results.

Test Program Conclusions

Tables 2C-2 and 2C-3 summarize relative filter media cleanability characteristics test results. Cleanability is represented by cleandown pressure drop (IWG) where a minimum value is most favorable, and cleaning event time interval (minutes) where a maximum value is most favorable. Separate tabulations are provided to account for gross differences of test particulate feed rate (< 7.7 grains/ACF and > 7.7 grains/ACF) which was not effectively controlled during the testing program.

The two separate tables apply to test operation without and with Electrostatic Enhancement operation. Table values are averages for less significant variations of test particulate feed rate and for different test particulate composition which was not perceived to be a significant operating variable.

A suggestion based upon these characteristics is that the 12/22 micron porosity filter media displayed the most favorable cleanability characteristics for both without and with Electrostatic Enhancement operation. The test results also suggest that use of Electrostatic Enhancement operation improved filter media cleanability.

A P P E N D I X 2C

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TABLE 2C-1
SUMMARY OF TEST OPERATING CONDITIONS AND TEST RESULTS
MICROSYSTEM/PATCH TEST FACILITY

FILE: SCSC01

TEST SERIES	004	004	004	004	004	004
TEST NUMBER	001	002	003	004	005	006
TEST DATE	2/28/91	2/28/91	2/28/91	2/28/91	3/1/91	3/5/91
FILTER MEDIA	DEKIPORE	DEKIPORE	DEKIPORE	DEKIPORE	DEKIPORE	DEKIPORE
	PR100	PR100	PR100	PR100	PR100	PR100
FILTER MEDIA PORESIZE, MICRONS	12/22	12/22	12/22	12/22	12/22	12/22
AIR FLOW, FPM	5.0	10.0	10.0	10.0	10.0	10.0
AIR FLOW, ACPH	2.5	5.0	5.0	5.0	5.0	5.0
AIR PULSE PRESSURE, PSIG	80 TO 80	80	80	80	80	80
AIR PULSE DUTY, SECONDS	0.6	0.6	0.6	0.6	0.6	0.6
HEAT PRESSURE DROP SET, INH	5.0, 2.0	5.0	5.0	5.0	5.0	5.0
TEST PARTICULATE COMPOSITION	ALUMINA & FLYASH (A)	ALUMINA & FLYASH (A)	ALUMINA & FLYASH (A)	ALUMINA & FLYASH (A)	ALUMINA & FLYASH (A)	ALUMINA & FLYASH (A)
TEST PARTICULATE, SP:BP	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4
TEST PARTICULATE, GRAINS/ACF	10.0	5.4	5.8	3.1	4.4	9.1
ONLINE CLEANING	YES	NO	NO	NO	NO	NO
OFFLINE CLEANING	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2
ELECTROSTATIC ENHANCEMENT USED	NO	NO	NO	YES	YES	NO
INLET DUCT, KV	-	-	-	-11.0	-11.0	-
FILTER MEDIA, KV	-	-	-	-	-	-
AVERAGE CLEANING PRESSURE DROP, INH	-	0.5	0.6	0.4	0.4	0.2 TO 1.0
MAXIMUM EFFECTIVE CLEANING PRESSURE DROP, INH	0.2	-	-	-	-	-
MINIMUM EFFECTIVE CLEANING PRESSURE DROP, INH	4.7	-	-	-	-	-
NUMBER CLEANING EVENTS, N	-	10	10	7	6	25
NUMBER CLEANING EVENT TIME INTERVALS, (N-1)	-	9	9	6	5	24
TOTAL TIME FOR (N-1) INTERVALS, MINUTES	-	201	137	286	182	163
AVERAGE TIME PER INTERVAL, MINUTES	-	22.3	16.8	47.7	36.4	6.8
ASH ONLY ESCAPE, GRAINS/ACF	-	-	-	-	-	-
ASH ONLY COLLECTION EFFICIENCY, %	-	-	-	-	-	-

NOTES:

- (A) 90 MICRON MHD ALUMINA MIXED WITH 15 MICRON MHD COAL FLYASH
(B) COPPER OXIDE COATED ALUMINA AND CNG FUEL ASH.
RECOVERED FROM SINGLE CYLINDER CNG FUEL DIESEL ENGINE SLIPSTREAM TESTING.
30 MICRON MHD
(C) COPPER SULFATE COATED ALUMINA (APPROXIMATE 90 MICRON MHD) MIXED WITH COAL FLYASH (15 MICRON MHD)
(D) COPPER SULFATE COATED ALUMINA (APPROXIMATE 90 MICRON MHD) MIXED WITH COAL FLYASH (15 MICRON MHD).
60 MICRON MHD MIXTURE

* TABLE 2C-1A *

004	004	004	004	004	004	004
007	008	008	010	011	012	013
3/5/91	3/7/91	3/11/91	3/12/91	3/13/91	3/14/91	3/18/91
BEKIPORE	BEKIPORE	BEKIPORE	BEKIPORE	BEKIPORE	BEKIPORE	BEKIPORE
PR100	PR100	PR100	PR100	PR100	PR100	PR100
12/22	12/22	12/22	12/22	12/22	12/22	12/22
10.0	10.0	10.0	10.0	10.0	10.0	10.0
5.0	5.0	5.0	5.0	5.0	5.0	5.0
00	00	00	00	00	00	00
0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	5.0	5.0	5.0	5.0	5.0	5.0
ALUMINA & FLYASH (A)	ALUMINA & FLYASH (A)	CUO/ALUMINA & CHS ASH (B)	CUO/ALUMINA & CHS ASH (B)	CUO/ALUMINA & CHS ASH (B)	CUO/ALUMINA & CHS ASH (B)	ALUMINA & FLYASH (A)
5.0:0.4	5.0:0.4	-	-	-	-	-
12.3	9.5	9.4	4.9	4.8	4.9	8.2
NO	NO	NO	NO	NO	NO	NO
YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2
YES	YES	NO	YES	NO	YES	YES
-11.0	-11.0	-	-9.5	-	-12.0	-10.0
-	-	-	-	-	-12.0	-10.0
0.2 TO 1.0	0.2 TO 2.0	0.2 TO 1.8	0.2 TO 1.5	0.4 TO 1.9	0.4 TO 1.3	0.3 TO 1.9
-	-	-	-	-	-	-
-	-	-	-	-	-	-
23	20	28	15	20	6	25
22	19	27	14	19	5	24
202	200	176	206	132	108	109
9.2	11.0	6.5	14.7	8.9	33.8	7.9
-	-	-	-	-	-	-
-	-	-	-	-	-	-

ALUMINA & FLYASH (A)		ALUMINA & FLYASH (A)		CUBO4/ALUMINA & FLYASH (C)		CUBO4/ALUMINA & FLYASH (C)		CUBO4/ALUMINA & FLYASH (C)		CUBO4/ALUMINA & FLYASH (C)		CUBO4/ALUMINA & FLYASH (C)	
004	014	004	014	004	014	004	014	004	014	004	014	004	014
3/22/91	4/2/91	5/2/91	5/13/91	5/13/91	5/13/91	5/13/91	5/13/91	5/13/91	5/13/91	5/13/91	5/13/91	5/13/91	5/13/91
FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS	FLUID DYNAMICS
ES75	ES75	ES75	ES75	ES75	ES75	ES75	ES75	ES75	ES75	ES75	ES75	ES75	ES75
20	20	20	20	20	20	20	20	20	20	20	20	20	20
10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
00	00	00	00	00	00	00	00	00	00	00	00	00	00
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4
10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1
YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2	YES 2
NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.3 TO 2.3	0.3 TO 2.3	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1	0.3 TO 2.1
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	25	25	25	25	25	25	25	25	25	25	25	25	25
24	24	24	24	24	24	24	24	24	24	24	24	24	24
110	110	110	110	110	110	110	110	110	110	110	110	110	110
4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.31E-3	1.31E-3	7.20E-4	7.20E-4	1.11E-3	1.11E-3	1.11E-3	1.11E-3	1.11E-3	1.11E-3	1.11E-3	1.11E-3	1.11E-3	1.11E-3
99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90

004 022 5/25/91 FLUID DYNAMICS	004 023 5/25/91 FLUID DYNAMICS	004 024 6/3/91 FLUID DYNAMICS	004 025 6/5/91 FLUID DYNAMICS	004 026 6/6/91 FLUID DYNAMICS
ES74	ES74	ES74	ES74	ES74
5/6	5/6	5/6	5/6	5/6
10.0	10.0	10.0	10.0	10.0
5.0	5.0	5.0	5.0	5.0
60	60	60	60	60
0.6	0.6	0.6	0.6	0.6
5.0	5.0	5.0	5.0	5.0 AND 7.0
CUBO4/ALUMINA & FLYASH (C)	CUBO4/ALUMINA & FLYASH (C)	CUBO4/ALUMINA & FLYASH (D)	CUBO4/ALUMINA & FLYASH (D)	CUBO4/ALUMINA & FLYASH (D)
5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4	5.0:0.4
8.7	9.7	10.3	9.0	9.7
NO	NO	NO	NO	NO
YES 2	YES 2	YES 2	YES 2	YES 2
YES	NO	NO	YES	YES
-11.0	-	-	-11.0	-10.5
-11.0	-	-	-11.0	-10.5
1.8 TO 3.4	1.7 TO 3.8	2.1 TO 3.9	1.2 TO 3.0	1.5 TO 4.3 AND 4.0 TO 4.7
-	-	-	-	-
-	-	-	-	-
20	20	20	20	48 AND 12
19	19	19	19	47 AND 11
211	92	84	210	258 AND 130
11.1	4.8	4.4	11.1	5.5 AND 11.8
5.22E-3	2.12E-4	6.70E-4	6.50E-5	-
99.99	99.97	99.99	99.99	-

TABLE 2C-2
 MICROSYSTEM/PATCH TEST FACILITY
 SUMMARY OF FILTER MEDIA CLEANABILITY CHARACTERISTICS

WITHOUT ELECTROSTATIC ENHANCEMENT OPERATION

 FILE: SC2CD2

FILTER MEDIA POROSITY, MICRONS	TEST PARTICULATE FEED RATE, GRAINS/ACF				> 7.7 CLEANING EVENT TIME INTERVAL, MINUTES
	< 7.7 CLEANDOWN PRESSURE DROP, IWG	< 7.7 CLEANING EVENT TIME INTERVAL, MINUTES	> 7.7 CLEANDOWN PRESSURE DROP, IWG		
5/6	-	-	2.6		7.0
12/20	0.8 *	13.1 **	1.0 *		6.8
20	-	-	1.2		7.2
30	2.2	4.8	-		-

* NOTE: BEST OPERATING CHARACTERISTIC-MINIMUM VALUE
 ** NOTE: BEST OPERATING CHARACTERISTIC-MAXIMUM VALUE

 * TABLE 2C-2 *

TABLE 2C-3
 MICROSYSTEM/PATCH TEST FACILITY
 SUMMARY OF FILTER MEDIA CLEANABILITY CHARACTERISTICS

WITH ELECTROSTATIC ENHANCEMENT OPERATION

 FILE: SC2CD3

FILTER MEDIA POROSITY, MICRONS	TEST PARTICULATE FEED RATE, GRAINS/ACF			
	< 7.7 CLEANDOWN PRESSURE DROP, IWG	< 7.7 CLEANING EVENT TIME INTERVAL, MINUTES	> 7.7 CLEANDOWN PRESSURE DROP, IWG	> 7.7 CLEANING EVENT TIME INTERVAL, MINUTES
5/6	2.0	17.1	2.5	9.2
12/20	0.6 *	33.1 **	1.1 *	9.4
20	-	-	1.3	4.2
30	-	-	1.8	11.6 **

* NOTE: BEST OPERATING CHARACTERISTIC-MINIMUM VALUE

** NOTE: BEST OPERATING CHARACTERISTIC-MAXIMUM VALUE

 * TABLE 2C-3 *

MICROSYSTEM PATCH TEST #1 (2-25-91)

BEKIPORE ST 25GFX (12-22 MICRON) A/C = 5

* FIGURE 2C-2 *

MICROSYSTEM PATCH TEST #2 (2-26-91) BEKIPORE ST 25GFX (12-22 MICRON) A/C = 10

 * FIGURE 2C-3 *

MICROSYSTEM PATCH TEST #3 (2-26-91)
BEKIPORE ST 25GFX (12-22 MICRON) A/C = 10

MICROSYSTEM PATCH TEST #4 (2-28-91)
BEKIPORE ST 25GFX (12-22 MICRON) A/C = 10

* FIGURE 2C-5 *

MICROSYSTEM PATCH TEST #5 (3-1-91)
BEKIPORE ST 25GFX (12-22 MICRON) A/C=10

MICROSYSTEM PATCH TEST #6 (3-5-91)
BEKIPORE ST 25GFX (12-22 MICRON) A/C=10

* FIGURE 2C-7 *

MICROSYSTEM PATCH TEST #7 (3-5-91)

BEKIPORE ST 25GFX (12-22MICRON) A/C=10

MICROSYSTEM PATCH TEST #8 (3-7-91)

BEKIPORE ST 25GFX (12-22MICRON) A/C = 10

* FIGURE 2C-9 *

MICROSYSTEM PATCH TEST #9 (3-11-91)
BERIPORE ST 25CFX (12-22MICRONS) A/C=10

MICROSYSTEM PATCH TEST #10 (3-12-91)

BEHPORE ST 25GFX (12-22MICRON) A/C=10

MICROSYSTEM PATCH TEST #11 (3-13-91)
BEKIPORE ST 25GFX (12-22MICRON) A/C=10

* FIGURE 2C-12 *

MICROSYSTEM PATCH TEST #12 (3-14-91)
BEKIPORE ST 25GFX (12-22MICRON) A/C=10

* FIGURE 2C-13 *

MICROSYSTEM PATCH TEST #13 (3/18/90)
BEKIPORE ST 25CFX (12-22MICRON) A/C = 10

* FIGURE 2C-14 *

MICROSYSTEM PATCH TEST #14 (3/22/91)
F.D.#E875/#1/(20MICRON) A/C=10

MICROSYSTEM PATCH TEST #15 (4/2/91)
F.D./E875#1(20MICRON) A/C=10

* FIGURE 2C-16 *

MICROSYSTEM PATCH TEST #16
FD/E875#1(20M)/CuSO4-Al2O3/6.5%CuO&ASH-A/C=10

* FIGURE 2C-17 *

MICROSYSTEM PATCH TEST #17

FD/E876#1(30M)/CuSO4-Al2O3/6.5%CuO&ASH-A/C=10

MICROSYSTEM PATCH TEST #18 (5-15-91) F.D.(E876/#1/30MICRON)A/C=10

 * FIGURE 2C-19 *

MICROSYSTEM PATCH TEST #19 (5-16-91)
F.D./E874/#1(5-6 MICRON)A/C=10

* FIGURE 2C-20 *

MICROSYSTEM PATCH TEST #20 (5-20-91)
F.D.(E874/#1/5-6MICRON)A/C=10

* FIGURE 2C-21 *

MICROSYSTEM PATCH TEST #22 (5-23-91)
F.D.(E874#1/5-6MICRON) A/C=10

* FIGURE 2C-22 *

MICROSYSTEM PATCH TEST #23 (5-28-91)
F.D.(E874#1/5-6MICRON) A/C=10

MICROSYSTEM PATCH TEST #24 (6-3-91)
FD(E874#1/5-6MICRON) A/C=10

* FIGURE 2C-24 *

MICROSYSTEM PATCH TEST #25 (6-5-91)

FD(E874#1/5-6MICRON)/A/C=10

MICROSYSTEM PATCH TEST #26 (6-6-91)
F.D.(E874/#1/5-6MICRON)/A/C=10

* FIGURE 2C-26 *

TAB 5

**DOE/GETS TOPICAL REPORT
CHAPTER 2D**

CHAPTER 2D

Commensurate with Task 2, Emissions Applied R&D

Task 2.2.1 & 2.2.2

Laboratory cold flow testing of various candidate Emissions Control Concepts

Cold Flow Envelope Barrier Filter using Electrostatic Enhancement Operation:

Test Facility:

Following the completion of the Microsystem/Patch facility test program, the merit of Electrostatic Enhancement operation was judged to be inconclusive. Further investigation of this phenomenon was performed by reactivating operation of the 500 ACFM cold flow Envelope Filter facility which was modified to accommodate Electrostatic Enhancement operation. The Envelope Filter, previously operated in a top inlet/side outlet configuration, was modified to a side inlet/top outlet configuration as described by Figure 2D-1 for expediency of installation of the modifications. Modifications included:

Installation of a 12 inch long (in the direction of gas flow) transparent duct to accommodate installation of a "precharger" emitting electrode system.

Installation of continuous turning vanes in the filter inlet plenum to force gas flow to enter the filter perpendicular to the inlet face of the filter envelopes.

Installation of a "precharger" emitting electrode system. Two different emitter configurations were tested. The initial configuration installed and tested was a mast arrangement using six 3/16 inch square twisted rods, as illustrated by Figures 2D-2 and 2D-3. The facility was also tested using an emitting electrode consisting of an eight rod mast arrangement to which was attached sharp point emitters pointing upstream, as illustrated by Figures 2D-4 and 2D-5. In the case of both emitting system configurations, high voltage charging was connected to only the emitter by the use of high voltage insulators. All other parts of the filter system were connected to relative ground potential.

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A perforated plate was installed 2 inches upstream of the emitter electrode and was connected to ground potential to complete the "precharger" field circuit. The perimeter of the perforated plate was blocked to provide a sheltered zone outside of the effective "precharger" field.

The configuration of the filter envelopes was exactly the same as employed for the conventional envelopes for the last testing of the cold flow Envelope Filter, Tests 003/121 through 135. The envelope which was modified for the last testing program was returned to a conventional configuration and installed with Fluid Dynamics 10-12 micron porosity filter media. All installed envelopes used this same type filter media.

Discussion of Test Results

An initial test was the determination of the pressure drop characteristic of the reconstructed Envelope Filter configuration. As illustrated by Figure 2D-6, a pressure drop of 0.16 IWG was obtained at 500 ACFM process air flow through the cleaned filter media. This characteristic was essentially identical to the 0.2 IWG pressure drop characteristic obtained in previous Envelope Filter Test 003/121 when the 10-12 micron porosity filter media was first installed.

In consideration of the modifications which were performed to the filter inlet plenum, velocity distribution tests were performed of the process air flow upstream of entry into the filter envelope matrix. Figures 2D-7 through 10 illustrate horizontal and vertical distributions of gas flow for two process air flow rates of 580 ACFM and 400 ACFM. Both air flow operating conditions produced similar air flow distribution characteristics. Horizontal distribution of air flow was very uniform across the width of the filter. Vertical distribution of air flow was not as uniform, as a consequence of the configuration of the turning vanes installed in the filter inlet plenum. A region of excessive air flow occurred near the bottom of the envelopes, at elevation "L". However, the overall air flow distribution characteristics were judged to be satisfactory for operation of the Envelope Filter.

Initial Test 136 was performed with the modified Envelope Filter configuration, but without Electrostatic Enhancement in operation. 500 ACFM process air flow, 5 IWG high pressure drop cleaning initiation, and use of 5:0.2 SP:EP mixture ratio of alumina powder and silica powder at a test particulate feed rate of 5 grains/ACF were consistent with previous test series Envelope Filter operating conditions. However, a cleaning air pulse ontime of 1.0 seconds was a departure from previous test conditions which were generally limited to a maximum of 0.6 seconds.

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Test operating conditions and test results for all tests conducted are summarized by Table 2D-1. Test results of individual tests are illustrated by a graph of Filter Pressure Drop vs. Test Time. These documentations are included in Appendix 2D.

Conventional automatic online cleaning at an initial pulse air pressure of 25 PSIG failed to produce any filter media cleandown. Pressure was increased to 50 PSIG, and envelopes continued to be cleaned by automatic online. A cleandown pressure drop of 2.0 IWG was obtained. At test time 77 minutes, cleaning was changed to a manual online procedure still using 50 PSIG pulse air pressure. Each of the four envelopes were cleaned in rapid succession, instead of only one envelope being cleaned as for automatic operation. There was a significant benefit to this changed cleaning operation, as shown by stable cleandown pressure drop reduced to 1.0 IWG.

Another observation of Test 136 was a significant amount of test particulate dropout in the low process air flow velocity filter inlet plenum and in the inlet plenum duct extension for accommodation of the "precharger" emitter. As a result, the test particulate feed rate was less than planned, based upon inventory of the filter hopper recovery. The drop out was allowed to remain in the filter, and subsequent tests were able to achieve the desired particulate feed rate as the drop out reached an equilibrium amount.

Test 137 was identical to Test 136, except that all cleaning was performed at 50 PSIG pulse air pressure using the manual procedure for cleaning all four envelopes which started at the end of Test 136. All subsequent testing was performed using the optimized procedure. Cleandown pressure drop at the beginning of the test was 1.5 IWG, but increased to a stable equilibrium value of 2.5 IWG by the end of the test.

Test 138 employed Electrostatic Enhancement operation. "Precharger" voltage ranged between -40 KV and -25 KV, as limited by arcing from the emitter to particulate build-up on the upstream perforated plate. These voltage operating conditions greatly exceeded the approximate -10 KV voltage operating condition of the previously tested Microsystem/Patch test facility. All other operating conditions for Test 138 were identical to Test 137.

Cleandown pressure drop results of Test 138 were inferior to the results of Test 137, which did not employ Electrostatic Enhancement operation. Initial cleandown pressure drop was 1.8 IWG, but gradually increased to 4.5 IWG at the end of the test. Also, cycle time interval between cleaning events was inferior to the results of Test 137.

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CHAPTER 2D**

Test 139 was identical to Test 137 and did not employ Electrostatic Enhancement operation. Test results were inferior to Test 137, but were similar to Test 138, which did use Electrostatic Enhancement. Test 139 definitely did not achieve stable cleandown pressure drop operation.

Operating conditions for Test 140 were identical to Test 139, including use of Neutralite filter media precoat treatment. Test 140 results were very similar to Test 139.

Test 141 was another duplication of previous Tests 139 and 140 not using Electrostatic Enhancement, except that cleaning air pulse air pressure was increased from 50 PSIG to 60 PSIG. There was little benefit obtained from this changed operating condition, since cleandown pressure drop only decreased to an unstable 3.8 IWG at the end of the test.

Operating conditions for Test 142 were the same as for Test 141 including use of 60 PSIG pulse air pressure. Test 142, however, employed Electrostatic Enhancement operation. Although cleandown pressure drop deteriorated to 3.4 IWG at the end of the test, the test duration was limited to only 40 minutes of operation. After 40 minutes of operation, Test 141 cleandown pressure drop had deteriorated to only 2.2 IWG cleandown pressure drop. Therefore, Test 142 did not reflect any improvement from the results of Test 141 as a consequence of the use of Electrostatic Enhancement.

A significantly changed operation condition for Test 143 was a reduction of process air flow to 400 ACFM, 8.0 FPM filtration velocity. This test did not employ Electrostatic Enhancement operation, and all other operating conditions were the same as for Tests 141 and 142.

Test 143 was a long test of 230 minutes duration at the end of which cleandown pressure drop appeared to have stabilized at approximately 3.5 IWG. To this extent, Test 143 was a first successful test run.

Test 144 began as a repeat of Test 143 operating conditions with the addition of Electrostatic Enhancement operation. Initial operation, at a high pressure drop cleaning initiation set point of 5.0 IWG, resulted in a cleandown pressure drop of 2.0 IWG for several cleaning event cycles. However, it is unlikely that this operation represented a stabilized operating condition after so short a time of operation. After the fourth cleaning event, the high pressure drop setpoint was increased from 5.5 IWG to 10.0 IWG. Several additional cleaning event cycles were operated, during which cleandown pressure drop increased from 4.0 IWG to 5.2 IWG. This operation did not represent stabilized operation.

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Operation of Electrostatic Enhancement operation for all tests so far was hampered by electrical arcing from the high voltage emitter, to particulate build-up on the upstream perforated plate, and, therefore, limited the magnitude of the applied voltage. An effort was made to avoid the particulate build-up on the perforated plate by increasing the process air flow velocity passing through the perforated plate. This was performed by installing additional blockage of the perforated plate to create a gross reduction of the free area, as illustrated by Sketch Figure 2D-0. The effect of this modification was to change the average process air flow velocity passing the emitter from 124 FPM to 301 FPM, and the average velocity passing through the perforated plate from 368 FPM to 893 FPM for operation with 400 ACFM process air flow.

Test 145 was performed as a determination of operating results without Electrostatic Enhancement in operation. Other than the perforated plate modification, Test 145 was a duplication of Test 143 operating conditions.

Test 145 ran for a duration of approximately 100 minutes and obtained cleandown pressure drop test results which ranged from an initial 1.5 IWG to an end of test value of approximately 3.5 IWG. This was of suspect stability. It was inconclusive if these test results were inferior to the results of Test 143, which had a better cleandown pressure drop of 1.8 IWG after 100 minutes of operation and a stabilized cleandown pressure drop of approximately 3.5 IWG after 230 minutes of operation.

Test 146 was performed at test operating conditions which duplicated Test 145, but with Electrostatic Enhancement placed in operation. Cleandown pressure drop test results of Test 146 were virtually identical to Test 145. However, there did appear to be some merit to the use of Electrostatic Enhancement operation, as shown by extended average cycle time between cleaning events.

Test 147 was performed at the same operating conditions as previous Test 145, without use of Electrostatic Enhancement operation, but with exception in regard to the test particulate operating condition. All previous tests had used a test particulate consisting of a 5:0.2 mixture ratio of 52 micron MMD alumina and 3.7 micron MMD silica. Beginning with Test 147 through Test 156, test particulate was changed to only copper sulfate coated alumina with an MMD of 58 microns. There was no fine silica powder included in this test particulate to simulate CWS fuel ash.

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Test 147 produced a dramatic improvement of test results as a consequence of the more favorable test particulate operating condition. Starting from an initial cleaned pressure drop of 2.0 IWG, it required 156 minutes of operation to initiate the first cleaning event. Cleandown pressure drop after the first cleaning event was down to 1.2 IWG, which was similar to typical values of 1.5 IWG obtained in previous test results. The cycle time interval for the pressure drop increase after the first cleaning was approximately 60 minutes. This test result cycle time interval was a significant improvement from any previous test results.

Test 148 repeated the favorable test operating conditions of Test 147, but with the addition of Electrostatic Enhancement operation. The results of Test 148 were inferior to Test 147 in regard to cleaning cycle time interval, and, therefore, were not an example of benefit derived from Electrostatic Enhancement operation. However, Test 148 did still represent improved test results relative to test results prior to Test 147.

Tests beginning with Test 149 were performed with a modification to the Envelope Filter configuration which was designed to provide an improvement of filter cleaning. The compact design of the filter, necessary to satisfy locomotive installation space constraints, required the envelopes to be spaced close together with only 2 inches of space between adjacent envelopes. As a result, during online cleaning particulate removed from an envelope tended to become redeposited on an adjacent envelope instead of becoming disengaged and deposited by gravity in the particulate collection hopper. This operation complication was compensated for during previous cold flow Envelope Filter testing by use of a top inlet/side outlet configuration. With use of a top air flow inlet arrangement, process air flows in a generally downward direction to reach the lower extremities of the envelope filter media. As the process air flows downward, it also tends to carry the particulate removed by cleaning in a downward direction, which is in the direction toward the particulate collection hopper. However, with the modification of the Envelope Filter to a side inlet configuration, there was no longer a mechanism for the process air flow to direct the particulate toward the collection hopper. A failure to effectively remove the particulate from the envelopes and deposit it in the collection hopper resulted in the particulate remaining on the envelope filter media with subsequent ineffective pressure drop cleandown.

The Envelope Filter configuration modification to improve cleandown pressure drop operation consisted of installing full vertical plane baffles between adjacent envelopes. In this manner, particulate removed by cleaning was intercepted by the baffle instead of being directed toward an adjacent envelope. This modification provided improved

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opportunity for particulate disengagement and gravity deposition in the collection hopper instead of reentrainment to adjacent filter media.

All other test operating conditions for Test 149 were identical to Test 147, as performed without the use of Electrostatic Enhancement operation.

In regard to cleandown pressure drop and cleaning event time interval, the results of Test 149 were judged to be inferior to the results of Test 147, as well as to Test 148, which was conducted using Electrostatic Enhancement operation. Accordingly, Test 149 did not demonstrate any benefit realized from the installation of the vertical baffles.

Test 150 was a duplication of Test 149 operating conditions, except that process air flow was increased from 400 ACFM to 500 ACFM. The purpose of the change of test operating conditions was to determine if installation of the vertical baffles could demonstrate merit for the more severe process air flow operating condition. As expected, the results of Test 150 were grossly inferior to the results of Test 149 as a consequence of the increased filtration velocity operating condition. The result of Test 150 was a 2.0 to 3.5 IWG cleandown pressure drop range which did not achieve equilibrium operation. This result did not represent any significant improvement from previous comparable process air flow operation test results which did not use the more favorable test particulate, the increased process air flow approach velocity, or the use of the vertical baffles.

Test 151 was a duplication of Test 150, except that Electrostatic Enhancement operation was used. These test results were similar to the results of Test 150 and, also, did not achieve equilibrium cleandown pressure drop.

Test 152 represented a major alteration of the Envelope Filter configuration and test operating conditions. As illustrated by sketch Figure 2D-28, approach process air flow was permitted to enter the Envelope Filter through only the upper two of the previously constructed five "windows" (See Test 145). This modification resulted in approach air flow velocity increasing by a factor of 5/2 relative to previous test operating conditions. Also, the modification returned some of the "downflow" process air flow direction which was perceived to be beneficial to Envelope Filter operation. The changed test operating condition resulted from increasing the number of cleaning air pulses which were initiated for each cleaning event. Previous test operation had consisted of cleaning each filter envelope one time by an air pulse, in rapid succession. The test procedure started in Test 152 was to clean each of the four envelopes three times, in rapid succession. Consequently, each cleaning event consisted of 12 air pulse cleanings. Envelope cleaning continued to use the filter configuration with vertical baffles installed between adjacent envelopes.

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A comparison of the results of Test 152 to previous Test 150, which did not include the major process air flow velocity change or use of Electrostatic Enhancement operation, does not indicate any significant change of cleandown pressure drop or cleaning event time interval test results. Therefore, there was no demonstration of merit for the configuration modification.

More Envelope Filter configuration changes were performed in preparation for Test 153. The modification of the filter inlet plenum, performed for Test 152, was removed and the plenum was returned to the configuration of Test 151. However, some additional changes were performed in an ongoing effort to create a more favorable process air flow environment for collected particulate to disengage and deposit in the collection hopper. A 4-inch high baffle was installed at the floor of the process air flow entrance into the filter and a baffle was installed at the midpoint of the collection hopper, extending $\frac{3}{4}$ of the depth of the hopper. The purpose of the two modifications was to inhibit process air flow recirculation within the collection hopper which had been observed to disrupt particulate deposition in the hopper. Another major modification was a change performed to the "precharger" emitter configuration. The previously installed twisted bar emitter was replaced by the sharp point configuration emitter. The purpose of this new electrode configuration was to achieve increased "precharger" field current density, and, therefore, more effective charging of the particulate entering the filter. Yet another preparation performed for Test 153 was removal of the filter envelopes, which were then washed to remove particulate blinding caused by previous test operation ineffective cleaning. The filter media envelopes used for the start of Test 153 represented essentially new filter media.

An initial observation of Test 153 was a starting pressure drop of only approximately 0.2 IWG which was quite similar to a value of 0.16 IWG for the new filter media. This 0.2 IWG value was a significant reduction from values of 1.0 IWG or greater which had occurred as starting pressure drop for the most recent 500 ACFM tests. This change provided an environment for more favorable filter media cleanability.

The results of Test 153 indicated very effective "precharger" performance. Operating voltage was slightly higher than was achieved in previous Electrostatic Enhancement operation tests, but current density was increased by a factor of approximately three. Cleandown pressure drop and cleaning cycle time interval test results were improved to 0.4 IWG and 94 minutes, respectively. These test results represented significant improvement from any previous test results, especially test results performed at the 500 ACFM process air flow operating condition.

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Test 154 repeated the operating conditions of Test 153, except that Electrostatic Enhancement operation was not used. The cleandown pressure drop result of Test 154 was a best yet accomplishment. Cleaning cycle time interval was not as good as Test 153, but still better than any previous 500 ACFM process air flow test result.

Test 155 was a repeat of Test 153 using Electrostatic Enhancement operation. However, "precharger" operating voltage and current density were not as favorable as were obtained in Test 153. Although better than any earlier 500 ACFM process air flow test results, the cleaning cycle time interval was not quite as good as was obtained in Test 153. The result for cleandown pressure drop test was equally satisfactory for Test 155 relative to Test 153.

Test 156 was another duplicate test of Electrostatic Enhancement operation Tests 153 and 155. This test was operated at "precharger" operating voltage and current density operating conditions which were within the range of conditions for Tests 153 and 155. The cleandown pressure drop test result was essentially identical to the compared test results. However, cleaning cycle time interval again deteriorated somewhat, following the progression from Tests 153 and 155. It is not understood why this phenomenon occurred.

Conclusions

The culmination of this test program task was able to demonstrate that a compact size design Envelope filter could operate with satisfactory filter media cleanability characteristics. Many innovative configuration variations were investigated and it was not determined which were significant to the successful operation. It was concluded that more definitive investigations would be more appropriately performed in a larger size and/or one more representative of true operating conditions. Benefit realized from the use of Electrostatic Enhancement was still inconclusive.

A P P E N D I X 2D

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TABLE 2D-1

SUMMARY OF TEST OPERATING CONDITIONS AND TEST RESULTS
FOR 500 ACFM COLD FLOW ENVELOPE FILTER MODIFIED FOR ELECTROSTATIC ENHANCEMENT OPERATION
FILE: SC2DD1

	005	005	005	005
TEST SERIES	136	137	138	139
TEST NUMBER	9/5/91	9/9/91	9/11/91	9/11/91
TEST DATE	500	500	500	500
PROCESS AIR FLOW, ACFM	10.0	10.0	10.0	10.0
FILTRATION VELOCITY, FPM	155	155	155	155
PROCESS AIR FLOW VELOCITY AT EMITTER, FPM	-	-	-	-
ENVELOPE FILTER CONFIGURATION MODIFICATIONS:	-	-	-	-
	-	-	-	-
	25 & 50	50	50	50
PULSE AIR PRESSURE, PSIG	1.0	1.0	1.0	1.0
PULSE AIR ONTIME, SECONDS	1.0	1.0	1.0	1.0
PULSE AIR OFFTIME, SECONDS	5.0	5.0	5.0	5.0
HIGH PRESSURE DROP SET, IWG	ALUMINA & SILICA	ALUMINA & SILICA	ALUMINA & SILICA	ALUMINA & SILICA
TEST PARTICULATE TYPE	5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2
TEST PARTICULATE SP:EP	2.8	5.1	5.3	5.3
TEST PARTICULATE FEED RATE, GRAINS/ACF	300	NO	NO	300
NEUTRALITE PRECOAT, GRAMS	NO	NO	YES	NO
ELECTROSTATIC ENHANCEMENT USED	-	-	TWISTED BAR	-
EMITTER FRAME CONFIGURATION	-	-	-45 TO -25	-
EMITTER KV	YES 1	NO	NO	NO
CLEANING AUTOMATIC ONLINE	YES 4	YES 4	YES 4	YES 4
CLEANING AUTOMATIC ONLINE	-	1.5 TO 3.0	1.8 TO 4.5	1.5 TO 4.3
CLEANDOWN PRESSURE DROP RANGE, IWG	1.0	-	-	-
CLEANDOWN MAXIMUM EFFECTIVE, IWG	2.0	-	-	-
CLEANDOWN MINIMUM EFFECTIVE, IWG	-	3.9	1.9	2.0
AVERAGE CLEANING CYCLE TIME INTERVAL, MINUTES	10.8	-	-	-
MAXIMUM TIME INTERVAL, MINUTES	5.1	-	-	-
MINIMUM TIME INTERVAL, MINUTES	-	-	-	-

* TABLE 2D-1A *

005	005	005	005	005	005	005
140	141	142	143	144	145	145
9/13/91	9/16/91	9/18/91	9/18/91	9/27/91	10/2/91	
500	500	500	400	400	400	
10.0	10.0	10.0	8.0	8.0	8.0	
155	155	155	124	124	301	
-	-	-	-	-	BLOCKAGE	
-	-	-	-	-	OF	
-	-	-	-	-	PERFORATED PLATE	
50	60	60	60	60	60	
1.0	1.0	1.0	1.0	1.0	1.0	
1.0	3.0	3.0	3.0	3.0	3.0	
5.0	5.0	5.0	5.0	5.0 & 10.0	5.0	
ALUMINA & SILICA	ALUMINA & SILICA	ALUMINA & SILICA	ALUMINA & SILICA	ALUMINA & SILICA	ALUMINA & SILICA	
5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2	
5.3	5.2	5.0	5.0	5.3	5.3	
300	300	300	300	300	300	
NO	YES	YES	NO	YES	NO	
-	NO	NO	-	NO	-	
-	-	-	-	-	-	
NO	NO	NO	NO	NO	NO	
YES 4	YES 4	YES 4	YES 4	YES 4	YES 4	
1.5 TO 3.8	2.0 TO 3.4	1.0 TO 3.7	1.8 TO 2.2/5.0	1.5 TO 3.7	1.5 TO 3.7	
-	-	-	4.0 TO 5.2/10.0	-	-	
-	-	-	-	-	-	
2.4	3.0	4.5	11.2/5.0	3.7	3.7	
-	-	-	40.2/10.0	-	-	
-	-	-	-	-	-	

005	005	005	005	005	005
146	147	148	149	150	151
10/3/91	10/10/91	10/11/91	10/15/91	10/16/91	10/21/91
400	400	400	400	500	500
8.0	8.0	8.0	8.0	10.0	10.0
301	301	301	301	376	376
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
60	60	60	60	60	60
1.0	1.0	1.0	1.0	1.0	1.0
3.0	3.0	3.0	3.0	3.0	3.0
5.0	5.0	5.0	5.0	5.0	5.0
ALUMINA & SILICA	CUSO4/ALUMINA	CUSO4/ALUMINA	CUSO4/ALUMINA	CUSO4/ALUMINA	CUSO4/ALUMINA
5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2
5.0	5.1	5.0	5.0	3.9	3.8
300	300	300	300	300	NO
YES	YES	YES	NO	NO	YES
TWISTED BAR	TWISTED BAR	-	-	-	TWISTED BAR
-35 TO -30	-40 TO -55	-	-	-	-45 TO -40
NO	NO	NO	NO	NO	NO
YES 4	YES 4	YES 4	YES 4	YES 4	YES 4
1.5 TO 3.7	1.5	1.5 TO 1.8	2.0 TO 3.5	2.5 TO 3.8	2.5 TO 3.8
-	-	-	-	-	-
-	-	-	-	-	-
5.4	60.0	34.4	30.5	4.2	3.0
-	-	-	-	-	-
-	-	-	-	-	-

005	005	005	005	005
152	153	154	155	156
10/25/91	10/31/91	11/7/91	11/8/91	11/13/91
500	500	500	500	500
10.0	10.0	10.0	10.0	10.0
940	376	376	376	376
GROSS	REMOVE GROSS	-	-	-
BLOCKAGE OF	BLOCKAGE, INSTALL	-	-	-
PERFORATED PLATE	FILTER BAFFLES	-	-	-
60	60	60	60	60
1.0	1.0	1.0	1.0	1.0
3.0	3.0	3.0	3.0	3.0
5.0	5.0	5.0	5.0	5.0
CUSO4/ALUMINA	CUSO4/ALUMINA	CUSO4/ALUMINA	CUSO4/ALUMINA	CUSO4/ALUMINA
5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2	5.0:0.2
3.9	4.0	4.0	4.1	4.1
NO	NO	NO	NO	NO
NO	YES	NO	YES	YES
-	POINT ELECTRODE	-	POINT ELECTRODE	POINT ELECTRODE
-	-50 TO -34	-	-34 TO -31	-45 TO -35
NO	NO	NO	NO	NO
YES 3X4=12	YES 3X4=12	YES 3X4=12	YES 3X4=12	YES 3X4=12
1.8 TO 3.2	0.4	0.3	0.5	0.5
-	-	-	-	-
-	-	-	-	-
3.6	94.0	59.1	65.0	57.0
-	-	-	-	-
-	-	-	-	-

3/16" TWISTED WIRE

FRONT ELEVATION

TWISTED BAR ELECTRODE

- NOTES:
1. TACK WELD TWISTED ROD TO PIPE
 2. WELD PIPE FRAME
 3. ALL WELDS GROUND SOUND
 4. RESISTANCE IS FOR AMBIENT CONDITIONS ONLY
 5. USE HYPOTENSILE NEGATIVE DC 40-50KV POWER SUPPLY

TWISTED BARE ELECTRODE

NOTE: 1. PERFORATED PLATE MUST HAVE SOLID CONTACT WITH Casing FOR GOOD ELECTRICAL GROUND

POINT ELECTRODE

FRONT ELEVATION

POINT ELECTRODE

ENVELOPE FILTER/PRESSURE DROP VS CFM FD-F18T/10-12MICRON/END INLET-TOP OUTLET

* FIGURE 2D-6 *

34% RMS ENTERING ENVELOPE FILTER

580 ACFM PERCENT HORIZONTAL PROFILE

* FIGURE 20-7 *

34% RMS ENTERING ENVELOPE FILTER 580 ACFM PERCENT VERTICAL PROFILE

* FIGURE 2D-8 *

VERTICAL TRAVERSE POINTS

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

4 of 7

38% RMS ENTERING ENVELOPE FILTER

400 ACFM PERCENT HORIZONTAL PROFILE

* FIGURE 2D-9 *

38% RMS ENTERING ENVELOPE FILTER 400 ACFM PERCENT VERTICAL PROFILE

* FIGURE 2D-10 *

VERTICAL TRAVERSE POINTS

ENVELOPE FILTER TEST #141
VOL = 500 ACFM/Al2O3 & SILICA 5.0:0.2gr/ACFM

ENVELOPE FILTER TEST # 142 /PART.CHARGING

VOL = 500 ACFM/Al2O3 & SILICA 5.0:0.2gr/ACFM

 * FIGURE 2D-19 *

ENVELOPE FILTER TEST #145

VOL = 400 ACFM/Al2O3 & SILICA 5.0:0.2gr/ACFM

ENVELOPE FILTER TEST #146/PART.CHARGING
VOL = 400 ACFM/Al2O3 & SILICA 5.0:0.2gr/ACFM

ENVELOPE FILTER TEST #147

VOL. = 400 ACFM/Al₂O₃ COATED W/7.0% CuSO₄

ENVELOPE FILTER TEST #148 / PART.CHARGING
VOL.= 400 ACFM / Al2O3 COATED W/7.0% CuSO4

* FIGURE 2D-24 *

ENVELOPE FILTER TEST #149
VOL = 400 ACFM/Al2O3 @ 5.0 gr/ACFM

* FIGURE 2D-25 *

ENVELOPE FILTER TEST #150

VOL = 500 ACFM/Al2O3(7.0%CuSO4)4.0gr/ACFM

* FIGURE 2D-26 *

ENVELOPE FILTER TEST #151/PART.CHARGING VOL = 500 ACFM/Al2O3(7.0% CuSO4)

ENVELOPE FILTER TEST #152

VOL = 500ACFM/AI2O3 W/7.0% AS CuSO4

ENVELOPE FILTER TEST #153/PART.CHARGING

VOL = 500 ACFM/Al₂O₃ W/7.0% CuSO₄

* FIGURE 2D-30 *

ENVELOPE FILTER TEST #154 VOL = 500 ACFM/Al2O3 W/7.0% CuSO4

ENVELOPE FILTER TEST #155 / H.V.CHARGING
 VOL = 500 ACFM/AI2O3 W/7.0% CuSO4

ENVELOPE FILTER TEST #156/H.V.CHARGING

VOL = 500 ACFM/AI203 W/7.0% AS CuSO4

TAB 6

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CHAPTER 2E

CHAPTER 2E

Commensurate with Task 2, Emissions Applied R&D

Task 2.2.1 & 2.2.2

Laboratory cold flow testing of various candidate Emissions Control Concepts

Granular Bed Filter

Design of Cold Flow Test Facility

Consistent with the intent of the program work statement, program Task 2 included planned investigation of Granular Bed filtration as a third potential option for control of CWS fuel exhaust ash particulate and gaseous emissions, in addition to the previously discussed Cyclone alone and Envelope type barrier filtration. A cold flow Granular Bed filter test facility was designed to operate at an air flow range of 500 to 700 ACFM. The test facility was designed for installation and operation using the same GEESI laboratory forced draft blower, connecting ductwork, and back-up fabric filter system which was used for previous Cyclone and Envelope Filter test programs. The test facility design is described by GEESI Drawings S9513/FA860 through FA866, which are enclosed in Appendix 2E. The following is a description of design features of this test facility design.

Drawing FA860 illustrates a side elevation of the GBF. Air flow approach to the GBF was through a 6 inch diameter duct and entered the GBF casing through an inlet turning plenum. Air flow discharge from the GBF was also through a turning plenum and discharge to a 6 inch diameter connecting duct.

Drawing FA866 illustrates the configuration of the center internal inlet plenum and the two outside internal outlet plenums. The internal inlet plenum was designed with a solid top, open bottom, and with porous material attached to each side. Three interchangeable inlet plenums were designed with different width dimensions. The purpose of the different plenum width dimensions was to permit operation of the GBF with different granular bed thicknesses in the direction of air flow, ranging from 2 inches to 6 inches. GBF internal outlet plenums were fixed at the outer sidewalls. Each plenum was designed with a solid top, open bottom, and with porous material attached to the sides which faced toward the inlet plenum.

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CHAPTER 2E**

The GBF was designed to be filled with granular media to at least the top of the inlet and outlet plenums. The open bottoms of the plenums would become sealed by the angle of repose of the granular media. Also, the open bottoms in contact with the granular media provided an opportunity for any particulate deposition to report to the granular media inventory and not accumulate on a solid floor. Process air was designed to flow from the porous face of the inlet plenum to the porous faces of the outlet plenums. An alternative air flow path could also occur through the granular media from the open bottom of the inlet plenum to the open bottoms of the outlet plenums.

The GBF cold flow test facility was designed to operate with either a static bed of granular media, or with a continuous moving bed to replicate moving bed operation. For moving bed operation, granular media would be required to be filled in the head space cavity above the top of the internal inlet and outlet plenums. A metering device would also be required to be installed at the bottom flange of the GBF casing. Slow removal of granular media through the metering device would replace reacted sorbent granular media with fresh sorbent media from the head space reservoir.

The GBF facility was designed to have a normal air flow operating range of approximately 500 to 700 ACFM. For these operating conditions, face velocity of air flow entering the granular bed would be in the range of 50 to 70 FPM. Air flow velocity entering the internal outlet plenums would be in the range of 60 to 90 FPM.

The GBF was designed to operate as a collection device for CWS fuel exhaust ash particulate with a size of approximately 3.7 micron MMD. The GBF was designed for operation to determine particulate collection efficiency as a function of process air flow, granular media bed thickness, and granular media particle size distribution variables.

The GBF concept was also planned to be applicable to removal of SO₂ and NO_x constituents of the CWS fuel exhaust gas. For this purpose, the granular media would be composed of a reactive sorbent material, such as copper oxide, or a more practical coating of copper oxide on a substrate material such as alumina.

An appropriate granular media particle size was perceived to be in the range of 0.5 to 2.0 mm diameter (0.02 to 0.08 inch diameter). This media size was an appropriate compromise between particulate capture, process gas flow pressure drop, and sorbent reactivity. The design of the porous face materials to be attached to the internal inlet and outlet plenums required consideration of the particle size of the granular media to avoid plugging of the porous media as well as avoiding carryover of the granular media. It was proposed to consider the use of perforated material as well as mesh material for this purpose. Potential mesh material use could be in the range of 10 US

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mesh (2.0 mm aperture) for use with the coarser 2 mm media, to 35 US mesh (500 micron = 0.5 mm aperture) for the finer 0.5 mm media.

Granular Bed Filter testing

A program commitment to the design and construction of the cold flow GBF test facility was made in parallel to ongoing cold flow testing of the Envelope Filter. Testing of the Envelope Filter developed greater confidence for successful operation of this device, and a need to compress the program schedule necessitated a deletion of testing of the Granular Bed Filter. Construction of the GBF cold flow test facility had already been completed at the time of this decision. However, procurement of the porous material for the internal plenums and procurement of the granular media were aborted.

A P P E N D I X 2E

DRAWING LIST

(APPENDIX 2E)

DRAWING NUMBER

DRAWING SUBJECT

S9513/FA860

GRANULAR BED FILTER ASSEMBLY

FA861

GRANULAR BED FILTER DETAILS (INLET PLENUM)

FA862

GRANULAR BED FILTER DETAILS

FA863

GRANULAR BED FILTER DETAILS (INLET DUCT)

FA864

GRANULAR BED FILTER DETAILS (OUTLET PLENUM)

FA865

GRANULAR BED FILTER DETAILS (OUTLET PLENUM)

FA866

GRANULAR BED FILTER DETAILS (INLET PLENUM)

8

7

6

NOTE: ANY ATTACHING DUCTWORK
NOT SHOWN MUST BE PROPERLY
SUPPORTED. EXTERNAL LOADS
ON INLET AND OUTLET
DUCT SECTIONS ARE NOT
PERMISSIBLE

SIDE ELEVATION

ISO FILE NO. 513FAR60

	DESCRIPTION	DESCRIPTION	DATE
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
REVIEWED FOR ENGINEERING			
PROJECT MANAGER APPROVAL			
APPROVAL DATE			
INCH/POUND

1. FABRICATION TO BE IN ACCORDANCE WITH SPECIFICATION NUMBER A/SXX-9.
2. FOR WELDING SPECIFICATION, SEE SPECIFICATION NUMBER A/XX-003.
3. ALL MATERIAL TO BE: 10 GA. ASTM A-570. GRADE 36 UNLESS NOTED.
4. ALL PLATE MATERIAL TO BE ASTM A-36.
5. ALL STRUCTURAL MEMBERS TO BE ASTM A-36.
6. ALL PIPE TO BE ASTM A-120 UNLESS NOTED.
7. ALL PIPE FITTINGS TO ISO LB.
FLANGE FROM ASTM 1807, SCREWED
ANSI B16.3, UNLESS NOTED.
8. NO PAINT REQUIRED.
9. FOR LIST OF REFERENCE DRAWINGS AND QUANTITIES
SEE BILL OF MATERIAL A/BFA-20.

DATE	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	0	DESCRIPTION
					WILDERBACH RDS-6	DRAWN 7/17/80
					SS	
					210

<h1 style="text-align: center;">GE Environmental Systems</h1>			
<h2>GRANULAR BED FILTER ASSEMBLY</h2>			
<p>NAME</p> <p>THIS IS A WARNING OF A DANGEROUS SITUATION OF DEATH OR SERIOUS INJURY TO PERSONS. THE GRANULAR BED FILTER ASSEMBLY IS A PRESSURE CONTAINING VESSEL. IT IS NOT TO BE OPENED OR REPAIRED WITHOUT THE PROPER SAFETY PRECAUTIONS. THE GRANULAR BED FILTER ASSEMBLY IS A PRESSURE CONTAINING VESSEL. IT IS NOT TO BE OPENED OR REPAIRED WITHOUT THE PROPER SAFETY PRECAUTIONS. THE GRANULAR BED FILTER ASSEMBLY IS A PRESSURE CONTAINING VESSEL. IT IS NOT TO BE OPENED OR REPAIRED WITHOUT THE PROPER SAFETY PRECAUTIONS.</p>	<p>UNITS FOR CONSTRUCTION</p>		<p>SIZE</p>
<p>DESCRIPTION</p> <p>THIS IS A WARNING OF A DANGEROUS SITUATION OF DEATH OR SERIOUS INJURY TO PERSONS. THE GRANULAR BED FILTER ASSEMBLY IS A PRESSURE CONTAINING VESSEL. IT IS NOT TO BE OPENED OR REPAIRED WITHOUT THE PROPER SAFETY PRECAUTIONS. THE GRANULAR BED FILTER ASSEMBLY IS A PRESSURE CONTAINING VESSEL. IT IS NOT TO BE OPENED OR REPAIRED WITHOUT THE PROPER SAFETY PRECAUTIONS. THE GRANULAR BED FILTER ASSEMBLY IS A PRESSURE CONTAINING VESSEL. IT IS NOT TO BE OPENED OR REPAIRED WITHOUT THE PROPER SAFETY PRECAUTIONS.</p>	<p>APPROXIMATE WEIGHT (LBS)</p>	<p>APPROXIMATE VOLUME (GALLONS)</p>	<p>APPROXIMATE LENGTH (FEET)</p>
	<p>S9513</p>	<p>FA-860</p>	<p>0</p>
<p>SCALE - NONE</p>	<p>1</p>		

WGT 3123' 25' 10

Technical drawing of a rectangular plate. The drawing includes the following dimensions and labels:

- Overall Dimensions:**
 - Length: $2'-4\frac{1}{8}"$
 - Width: $2'-10\frac{1}{4}"$
- Internal Features:**
 - FLANGE "A":** Located at the top, with a width of $4\frac{1}{8}"$ and a height of $10\frac{1}{4}"$. It contains $5\frac{1}{8}"$ spaces and a $1\frac{1}{8}"$ gap.
 - FLANGE "B":** Located at the bottom, with a width of $4\frac{1}{8}"$ and a height of $10\frac{1}{4}"$. It contains $5\frac{1}{8}"$ spaces and a $1\frac{1}{8}"$ gap.
 - TOP, TOP & BOTTOM OF CHAINS:** Indicated by dashed lines and arrows.
 - HOLE:** A circular hole with a diameter of $7\frac{1}{16}"$ is shown on the right side.
- Other Labels:**
 - PLAN:** Located at the top left.
 - 100:** A label with an arrow pointing to the right side of the plate.

5 4 3 2 1

NOTES
1. FOR GENERAL NOTES SEE DRAWING E/FA-860

REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION
1		2		3		4		5	

GE Environmental Systems			
GRANULAR BED FILTER DETAILS			
DATE	SCALE	BY	CHKD
10/11/90	1/2" = 1'-0"	FA-861	0

001113L 1/2" = 1'-0"

311

2" x 1/4" -
FLAT BAR

2" x
FLAT

PLAN

HOPPER

AT END
& ON
CENTER

FLANGE "A"

CAD FILE NO. 513/A062				
REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION
DESIGNED BY				
CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR CONSTRUCTION				
PROJECT MANAGER APPROVAL				
APPROVAL DATE				
REWORKED

NOTE:
1. FOR GENERAL NOTES SEE E/FA-BB0.

<h1 style="text-align: center;">GE Environmental Systems</h1>			
<h2>GRANULAR BED FILTER DETAILS</h2>			
<p>THIS IS A SUMMARY OF A GRANULAR BED FILTER. IT IS NOT A DESIGN SPECIFICATION. IT IS A SUMMARY OF THE DESIGN AND CONSTRUCTION OF THE FILTER. IT IS NOT A DESIGN SPECIFICATION. IT IS A SUMMARY OF THE DESIGN AND CONSTRUCTION OF THE FILTER.</p>	DESIGN FOR CONSTRUCTION		DATE
	APPROVED BY	DESIGNED BY	DATE
400	S9513	FA-862	0

HEAD FILE NO: 513A863		DESCRIPTION		DESCRIPTION	
DESIGNED BY					
CHECKED BY					
REVIEWED FOR DESIGN					
REVIEWED FOR ENGINEERING					
PROJECT MANAGER APPROVAL					
APPROVAL DATE					
MICROFILMED

PLAN

SECTION

CAD FILE NO. 9137 ADD-1					
NAME OF	DESCRIPTION	DESCRIPTION			
DRAWN BY					
CHECKED BY					
APPROVED FOR DESIGN					
APPROVED FOR CONSTRUCTION					
PROJECT NUMBER APPROVAL					
APPROVAL DATE					
REVISIONS

1. FOR GENERAL NOTES SEE E/FA-860

[illegible]

02:10

NOTE:
1. FOR GENERAL NOTES SEE E/FA-860.

<h1 style="text-align: center;">GE Environmental Systems</h1>				
<h2>GRANULAR BED FILTER DETAILS</h2>				
<p>NOTE: This is a summary of a description. Please do not use this summary as a substitute for the actual drawing. The drawing is the only source of information for the design and construction of the filter. The drawing should be used to determine the filter design and construction details. The drawing should be used to determine the filter design and construction details. The drawing should be used to determine the filter design and construction details.</p>	DATE FOR COMPLETION		DATE	
	<input type="text"/>		<input type="text"/>	
	APPROVED BY	DRAWING NUMBER	REV.	
	S9513	FA-865	<input type="text"/>	
SCALE - NONE				☒

DAO FILE NO: 513FA686

REVISION	DESCRIPTION	REVISION	DESCRIPTION
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
REVIEWED FOR ENGINEERING			
PROJECT MANAGER APPROVAL			
APPROVAL DATE			
REWORK/REVISION			

[illegible]NOTES.
1. FOR GENERAL NOTES SEE E/A-860.

TAB 7

DOE/GETS TOPICAL REPORT
CHAPTER 2F

CHAPTER 2F

Commensurate with Task 2, Emissions Applied R&D.

Task 2.2.3, 2.2.4, & 2.2.5

Diesel engine hot gas testing of various candidate Emissions Control Concepts

Envelope Type Barrier Filter

Introduction

This phase of program activity was a size (CWS fuel diesel engine exhaust gas flow) and service (CWS fuel diesel engine operating conditions) progression from previously completed program tasks. The ultimate task objective was to process the entire exhaust gas flow of approximately 1700 ACFM at 700 F from a one cylinder CWS fuel test cell research diesel engine. Failing to achieve the ultimate objective, the Emissions Control system should be as large as possible, limited by engine test cell space constraints, to demonstrate a significant size scale-up from previously completed slipstream concept studies. The equipment to be included in this task system was planned to be completely self-supporting and capable of installation in the engine test cell adjacent to the operating research engine.

Planning for the installation of Emissions Control system equipment inside the test cell became very dependent upon available space which would not impact access to the engine. Also, planning was to be performed to permit installation of various Emissions Control concepts. The planning for this program task was performed in parallel with ongoing cold flow test investigations of the Envelope Filter concept. Although the Envelope Filter concept was a primary planned option for this size and service progression as well as eventual full size engine use, it was appropriate to make the test cell planning adaptable to other concepts, if required, or for other application interests.

Test Cell Modification Equipment

Plans for test cell modification equipment were limited to an engine gas flow capacity of 500 to 800 ACFM, which was commensurate with the size capacity of the previously planned and executed cold flow Emissions Control concepts. Emissions Control concepts which were included in planning were: Cyclone alone; Granular bed filter alone; Cyclone in combination with granular bed filter; and the primary concept of interest, Envelope Filter alone. General arrangements of these equipment concepts, as installed in the engine test cell along with other required support equipment, are described by GEESI drawings S9513/GA800 to 805, included in Appendix 2F. Design details of required support equipment are described by GEESI drawings S9513/FC801 to 804, and are also included

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CHAPTER 2F**

in Appendix 2F. Other support equipment included:

Exhaust gas flow control valve which was controlled by exhaust gas flow orifice flow meter. This valve actually functioned as a pressure reduction valve from the 22 PSIG engine exhaust source, and permitted the system components to be designed for only the expected system pressure drop to outlet atmospheric pressure.

Remote controlled exhaust gas system isolation valves.

Air preheater system - An electrical air preheater was installed to permit preheating of system ductwork and the Emissions Control device up to the expected 700 F temperature, prior to opening exhaust gas flow to the system. The purpose for this equipment was to avoid condensation of exhaust gases and to assist the stoichiometric reactions for SO_2 and NO_x reduction.

Sorbent feeder - A screw type feeder was installed to control the injection rate of sorbent into the exhaust gas entering the Emissions Control device. A requirement of this equipment was an ability to operate when discharging into a region under positive pressure. Two sorbent feeder configurations were planned. GEESI drawing S9513/GA801 illustrates the gravity feed configuration which was ultimately used for all tests. This configuration had the feeder discharge into a vertical pipe connected to the high velocity throat of a venturi, which was installed in the control device inlet duct. The location of the venturi was positioned to provide some "fly time" for the exhaust gas/sorbent reaction in addition to the residence time of the sorbent within the control device.

Positive displacement blower - A system was installed to provide pneumatic injection of sorbent into the control device inlet duct, using ambient air. This equipment was provided in the event the gravity feed system did not adequately disperse the sorbent in the exhaust gas flow. However, the pneumatic injection system, as described by GEESI Drawing S9513/GA805, was not a preferred operation system because of objectionable temperature dilution of the exhaust gas by the ambient temperature transport air, as well as the additional air flow which required treatment by the control device, which was already pressed to the maximum possible capacity by space limitations for installation of the control device.

Instrumentation and controls were installed to control such operating conditions as exhaust gas flow rate, sorbent injection rate, and ammonia injection rate, as well as such test results as gas temperature in the control device and exhaust gas composition at the control device inlet and at the control device outlet effluent. Test ports were also provided in the control device inlet and outlet

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ductwork for isokinetic sampling determination of particulate concentrations of exhaust gas ash and injected particulate. For the case of the Envelope Filter control device, controls were also provided for manual on demand cleaning of the filter media. Filter media cleaning by high pressure air reverse flow pulsing was controlled by variables such as pulse air pressure, pulse duration ontime, and pulse cleaning interval offtime.

500 ACFM Capacity Hot Gas Envelope Filter

The parallel path design of an Envelope Filter for single cylinder CWS fuel research diesel engine operation was very similar to the design executed for laboratory cold flow testing, except for material of construction modifications for 700 F operation. A design simplification for the hot gas design was a limitation to only an installation configuration for top inlet, downward gas flow, and side gas flow outlet. The filter design was also simplified by the elimination of unneeded and complicating filter width which was included as a contingency in the cold flow design. However, a design embellishment was the addition of an integral rupture port gas flow bypass from the filter inlet plenum to the filter outlet plenum. The bypass was provided as an ultimate fail-safe design in consideration of a filter casing designed for +50 IWG (1.8 PSIG), compared to a potential +22 PSIG engine exhaust gas discharge pressure. Although system controls were set to close the system isolation valves before the design pressure was exceeded, the bypass was provided for fail-safe operation in the event of a failure of the control system and blinding of the filter media causing the gas flow control valve to open to sustain the desired gas flow. This situation could eventually result in the full +22 PSIG pressure being subjected to the filter system.

Filter media selected for installation in the hot gas Envelope Filter, as supplied by Fluid Dynamics, was Dynaloy E874, constructed with Inconel fibers and having a porosity rating of 5 to 6 microns. This filter media was similar to one of the filter media investigated during the latter stages of the cold flow Envelope Filter testing.

Hot Gas Envelope Filter Test Plan

Planned emissions control testing of the single cylinder CWS fuel research engine did not permit unlimited opportunity for exploring operation variables. However, some opportunity was permitted for operation of the Envelope Filter in regard to sorbent use and filter cleaning. Also, operation of the Envelope Filter was varied in regard to the amount of engine exhaust gas diverted to the filter and the resulting filtration velocity through the filter media.

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Sorbent Use

All tests were performed using gravity particulate injection into the exhaust gas entering the Envelope Filter, in addition to the CWS fuel ash. All tests were also performed with Neutralite Aluminum Silicate precoating applied to the filter media during the time of air preheater operation, prior to exhaust gas operation.

The type of particulate injection during exhaust gas operation was a variable for the test program. Variables were: Copper oxide coated alumina powder, Sodium bicarbonate powder, Alumina powder alone, and Copper sulfate coated alumina representing reacted copper oxide coating sorbent. While the two former materials served the purpose of sorbent and CWS fuel ash diluent for enhancement of filter media cleaning, the latter two materials served only for the diluent purpose and did not provide any SO_2 sorbent property, although the copper sulfate did provide enhancement for NO_x reduction. The alumina alone was the same material which was utilized for the coating with copper oxide and copper sulfate. The source of the copper sulfate coated alumina was prepared in small batches in the GEESI laboratory. Subsequently, this material was recovered after test use, cleaned of CWS ash, and regenerated at elevated temperature to the desired copper oxide coating sorbent form for later test purposes. The laboratory preparations of copper oxide sorbent were necessary because a commercial production source for the desired sorbent material composition had not yet been determined. Another stoichiometric matter of interest was the use of ammonia injection for the purpose of reducing NO_x . The use of ammonia was investigated as an operation variable for the primary copper oxide coating sorbent, as well as for use with copper sulfate coating, sodium bicarbonate sorbent, and inert alumina.

Filter Media Cleaning

All filter media cleaning was performed starting at a plant air pressure source at 80 PSIG for a pulse duration of 2.5 seconds, during which the pressure decreased to 45 PSIG. The time interval between air pulse cleaning of adjacent filter envelopes was 8 seconds. However, the filter pressure drop at which cleaning of the filter media was initiated was a variable ranging between 9 IWG and 20 IWG for tests which produced significant test results. Other variables of filter cleaning operation were the number of times cleaning was cycled through the four filter envelopes and the use of offline cleaning for which exhaust gas flow was temporarily interrupted. Generally, all cleaning was performed for one cycle of the envelopes, as an online procedure. Use of more than one cleaning cycle and use of offline cleaning procedures were resorted to only during situations of ineffective cleaning performance.

Test Exhaust Gas Flow and Filtration Velocity

A planned design exhaust gas flow rate operating condition for the 50 sq ft. filter media Envelope Filter was 500 ACFM corresponding to a filtration velocity of 10.0 FPM. Tests which produced significant test results were conducted employing a range of gas flow/filtration velocity conditions between 420 ACFM/8.3 FPM and 530 ACFM/10.6 FPM. Other tests investigated gas flow conditions as low as 275 ACFM/5.5 FPM and as high as 580 ACFM/11.6 FPM.

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Discussion of Test Results

Discussed test operating conditions and test results are summarized by Table 2F-1 enclosed in Appendix 2F. Graphs of test conditions and results versus time are also enclosed.

Test Numbers HOT 001, 002, 003, and 004 were preliminary in nature and were useful to exercise the Emissions Control System equipment. These tests did not actively explore SO₂ reduction, as only one test, Test 003, utilized sorbent material (sodium bicarbonate).

Test Numbers HOT 005, 006, 007, and 009 were tests which produced significant test results. All of these tests utilized particulate injection with sorbent for reduction of SO₂ and/or NO_x. Also, all tests were performed at a gas flow operating condition resulting in a filtration velocity which was close to a commercial full size system 10 FPM requirement. All tests operated during many cleaning events, most of which were performed at cleaning initiation pressure drop conditions commensurate with expected commercial full size system operating conditions. All test filter media cleaning was performed as online operation.

Test HOT 005 was performed using copper sulfate/alumina sorbent/precoat injection. This was material produced for later regeneration and reuse as copper oxide/alumina sorbent. Although SO₂ concentration was not quantified during the test, NO_x was quantified and indicated a reduction of 38% to 88%, from an inlet concentration of 400 PPMV when using varied amount of ammonia injection. These test results approached expected performance for the use of ammonia injection. The variation of filter outlet NO_x concentration is illustrated by Figure 2F-16 in Appendix 2F. This figure shows a reduction of NO_x as the sorbent coating thickness on the filter media increased, with increasing filter pressure drop after each cleaning. Figure 2F-15 illustrates the history of filter pressure drop during the test which included three cleaning events. Each cleaning event produced very effective cleandown to a pressure drop <5 IWG. The particulate injection, at an injection rate of 5 grains/acf, was effective for enhancement of filter media cleaning.

A test result of 98.8% particulate collection efficiency did not attain an expected 99+%.

Tests HOT 006 and 007 were both conducted using sodium bicarbonate sorbent/precoat injection. Test 006 employed an injection rate which was commensurate with 190% of the stoichiometric requirement for SO₂ removal, while Test 007 employed a variable sorbent injection rate which resulted in a range from 0% to 295% of the stoichiometric requirement.

Both tests also employed intermittent ammonia injection to investigate NO_x reduction. Test 006 used as much as 99% of stoichiometric requirements, while Test 007 ammonia usage was as much as 180% of the stoichiometric requirement.

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CHAPTER 2F**

Both tests produced similar favorable test results for SO₂ reduction. Test 006 achieved 84% to 100% SO₂ reduction during test operation with continuous sodium bicarbonate injection, while Test 007 achieved 67% to 93% reduction with sorbent injection in operation. Both of these test results were commensurate with expected performance. Test 007 indicated reduced SO₂ reduction in the range of 41% to 52% when sorbent injection was not in operation.

In regard to NO_x reduction, Test 006 achieved 21% NO_x reduction when ammonia injection was in operation, while Test 007 achieved 24% to 29% NO_x reduction with ammonia injection, but essentially no reduction when ammonia^x was not operating. These NO_x reduction test results were much less than an expected 85% removal based upon the use of copper oxide sorbent.

Test 006 included four online cleaning events, three of which achieved satisfactory cleandown to about 5 IWG. In Test 007, there were three cleaning events and all but one achieved satisfactory cleandown to 5 IWG.

Both Test 006 and 007 produced particulate collection efficiency which was inferior to an expected 99+% collection efficiency.

Test 009 was conducted using copper oxide as the sorbent coated on alumina powder. This sorbent was regenerated from an initial coating of copper sulfate which was prepared for previous Test 005. Sorbent particulate feed rates ranged from none to 10 grains/ACF of filter inlet gas flow. At 10% of the particulate feed rate representing the amount of copper oxide coating, SO₂ removal stoichiometry as favorable as 512% occurred during test operation. Ammonia injection for NO_x reduction stoichiometry was as high as 81% during test operation.

Filter inlet SO₂ concentration was determined to be consistent with expected and previous test results. Filter inlet NO_x concentration was also determined to be an appropriate value. However, filter outlet SO₂ and NO_x concentrations produced very confusing test results. It is unknown if the gas composition analyzer malfunctioned, but only when connected to the filter outlet gas sampling location.

Indicated test results for filter outlet SO₂ concentration show SO₂ peaks as high as 1100 PPMV. It is inconclusive what² instigated these peaks, but an overlay of ammonia injection, sorbent injection, and filter pressure drop, with SO₂ and NO_x concentration suggests that the SO₂ peaks tend to coincide with the removal of sorbent from the filter media. ²This characteristic appears for the 2nd, 3rd, 5th and 6th cleaning events. The SO₂ peak did not occur for the 4th cleaning event because the gas analyzer was at that time connected to the filter inlet. There is no explanation for 1st cleaning event relationship to a SO₂ concentration peak. Also, none of the SO₂ concentration peaks appear to have any relationship to ammonia injection, because they appear both at times when ammonia injection was in operation as well as when ammonia injection was not in operation.

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Indicated test results for filter outlet NO_x concentration also show a series of peak concentrations at a level of 450 PPMV, which was essentially the same as the filter inlet NO_x concentration. The time scale of these NO_x peaks seems to be somewhat related to the SO₂ concentration peaks, but not related to the occasions of ammonia injection.

The only possible conclusion regarding Test 009 SO₂ and NO_x concentrations is that the results are not understood and should be disregarded.

Test 009 included six cleaning events, all of which were performed while sorbent/precoat particulate injection was being performed at concentrations of 3 grains/ACF and 10 grains/ACF. The first three of these cleaning events achieved effective cleandown pressure drop approaching or exceeding a satisfactory 5 IWG pressure drop. However, the last three cleanings were performed after sorbent/precoat particulate injection was stopped. It is significant that none of these last cleanings were capable of achieving effective cleandown. Therefore, it must be concluded that the use of continuous injection of sorbent/precoat particulate is essential to effective filter media cleaning.

Each of Tests 005, 006, 007, and 009 included determination of particulate collection efficiency of the filter media by determination of composite filter outlet particulate concentration comprising the injected sorbent/precoat as well as the CWS ash. The determination of particulate collection efficiency was performed in consideration of test operation variations of the sorbent/precoat particulate injection rate. Test results of particulate collection efficiency ranged between 96.1% and 98.8%, which were all inferior to an expected 99+% collection efficiency.

Additional hot gas Envelope Filter tests which were performed and are of some interest were Tests 008, 010, and 011. All of these tests were performed at gas flow operating conditions which were commensurate with expected commercial full size system operating conditions. Test 008 was performed using a small concentration of inert alumina powder particulate injection, but did not include use of any ammonia injection. This test did not include any determinations of gas SO₂ or NO_x composition. However, filter media cleaning and particulate collection^x efficiency were test diagnostics.

An initial online filter cleaning achieved a cleandown pressure drop to less than 5 IWG from a cleaning initiation pressure drop of 11.5 IWG. However, a second online cleaning, which was initiated at 14.8 IWG pressure drop, was not effective and achieved a cleandown pressure drop of only 13 IWG. The results of this test verify that a significant amount of continuous diluent particulate injection is required to achieve satisfactory cleaning of the filter media, when operating at high filtration velocity with CWS fuel ash particulate.

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Tests 010 and 011 were both performed using sodium bicarbonate sorbent/precoat particulate injection. Both tests employed variable particulate injection rates ranging between perceived excessive dilute and satisfactory amounts. Also, both tests were performed without and with the use of ammonia injection. Test 010 was started at a dilute 1.4 grains/ACF particulate injection rate. The first online cleaning event achieved a successful cleandown to about 5 IWG. However, the next cleaning event was much less successful and the third cleaning event did not achieve any cleandown.

Before attempting any additional cleaning events, the sorbent/precoat particulate feed rate was increased to a more appropriate concentration of 4.7 grains/ACF. However, when the next cleaning event was performed, it was again unsuccessful. This cleaning event was extended to continuous cleaning (repeated manual initiations of cleaning), but this procedure did not provide any cleandown benefit.

A final cleaning event consisted of offline cleaning. Gas flow was bypassed and the filter media was cleaned with no process gas flow to the filter media. After resuming the original 450 ACFM process gas flow, filter pressure drop was reduced to a satisfactory 5.9 IWG. During continued operation until the end of the test, the rate of filter pressure drop increase was less than was experienced during earlier test operation using the unsatisfactory dilute sorbent/precoat particulate feed rate.

SO₂ concentration of the filter inlet gas was determined to be 300 to 400 PPMV, and filter outlet SO₂ concentration was determined to be in the order of only 20 PPMV, regardless of filter pressure drop or sorbent/precoat feed rate, corresponding to an excellent 93% to 95% SO₂ removal.

Filter inlet NO_x was determined to be 400 to 420 PPMV. Filter outlet NO_x was determined to be in the order of 400 to 450 PPMV indicating that no NO_x reduction occurred during test operation when ammonia injection was not in operation. However, during a short period of operation with ammonia injection at a rate of 2 standard L/minute, filter outlet NO_x concentration decreased to 320 PPMV, which corresponded to approximately 10% NO_x reduction.

Composite filter outlet particulate concentration was determined to be 0.049 grains/ACF, corresponding to a particulate collection of 98.45%. This particulate collection efficiency was again inferior to an expected 99+%.

Test 011 was conducted at a gas flow of 540 ACFM, which was greater than the 450 ACFM condition used for Test 010. Test 011 also was started at a dilute sorbent/precoat particulate concentration of only 0.45 grains/ACF. An initial online cleaning initiated at 10.4 IWG pressure drop achieved satisfactory 6.1 IWG cleandown pressure drop. However, the next attempted online cleaning initiated at 12.0 IWG pressure drop failed to achieve any

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cleandown. Later, offline cleaning was initiated at a filter pressure drop of 12.9 IWG. This off line cleaning was successful. When gas flow was resumed at 540 ACFM, filter pressure drop was reduced to 5.7 IWG. Another online cleaning initiated at a pressure drop of 11.5 IWG was, again, completely ineffective. However, subsequent offline cleaning initiated at 16.0 IWG was effective when it achieved a pressure drop of 6.1 IWG after gas flow was restored. After completion of this offline cleaning, particulate injection was increased to a more appropriate 4.46 grains/ACF.

Two subsequent online cleaning events were performed at initiation pressure drops of 11.3 IWG and 10.8 IWG. Neither of these events achieved any significant pressure drop cleandown. However, it is interesting to note that since the particulate feed rate was increased, the rate of pressure drop rise was decreased. Another offline cleaning was performed at an initiation pressure drop of 13.1 IWG. Consistent with previous test experience, this cleaning was again successful, as indicated by a cleandown pressure drop of 6.1 IWG after gas flow was restored. After completion of the final offline cleaning event, the filter was operated in continuous online cleaning. However, the online cleaning was again ineffective, and filter pressure drop continued to increase until a pressure drop of 12.0 IWG was reached when the test was terminated.

Filter inlet SO_2 concentration for Test 011 was determined to be in the range of 300 to 330 PPMV, while filter outlet ranged between 100 PPMV when the dilute sorbent feed rate was in operation and a more favorable 20 PPMV when the sorbent feed rate was increased. This operation corresponded to a SO_2 removal range of 70% at the lower SO_2 stoichiometry, and 93% at the more favorable SO_2 stoichiometry operation.

Filter inlet NO_x was measured in the range of 540 to 670 PPMV. Filter outlet NO_x concentration, during the majority of test operation without ammonia injection, ranged between 540 and 670 PPMV, corresponding to 15% to 18% NO_x removal. During a short duration of ammonia injection, filter outlet NO_x concentration was decreased to 430 PPMV, resulting in a small improvement of NO_x removal to 29%.

Conclusions of Hot Gas Test Results

One obvious and consistent characteristic evidenced by the hot gas test results was a deficiency of particulate collection efficiency by the filter media. It is not understood why this occurred nor whether it was caused by seepage through the filter media or by leakage around the filter media. However, the former conclusion was assumed to be a worst case scenario which was considered in the selection of the filter media chosen for use in the full size Envelope filter design.

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Test results regarding cleanability of the filter media were mixed. Some test results, such as Tests 005 and 006, produced satisfactory on line cleanability test results, while other tests, such as Tests 004, 010, and 011, indicated unsatisfactory cleanability. Some of the factors which were investigated as variables, relative to cleanability, were:

Filtration velocity - Tests 004 and 011, which were performed at higher filtration velocity, indicated less ability for satisfactory cleandown.

Sorbent/Precoat particulate feed rate - Tests 009, 010, and 011, which investigated variable particulate injection rates, suggested that cleanability was enhanced by greater particulate injection.

Use of Neutralite precoat - All tests used Neutralite precoating prior to the start of CWS fuel ash operation, so it is not possible to compare operation with and without this procedure. However, all tests did produce an effective initial cleandown when the Neutralite coating was on the filter media.

Type of sorbent/precoat particulate - There is no indication of any benefit or detriment of any of the materials which were tested.

SO₂ reduction efficiency was not a clearly defined characteristic. Filter inlet SO₂ concentration was quite consistent for all tests. Most tests which used reactive sorbent achieved an expected 90% SO₂ removal. Test 007 also quantified the effect of sorbent stoichiometry relative to SO₂ removal. Unfortunately, Test 009, the only test to employ copper oxide² sorbent, failed to produce any useful test results regarding SO₂ removal.

NO_x reduction efficiency was also not a clearly defined characteristic. Filter inlet NO_x concentration was quite consistent, as was the case for filter inlet SO₂. However, filter outlet NO_x concentration and NO_x removal appeared to depend upon test operating conditions. The best results were achieved in Test 005 using copper sulfate particulate injection and ammonia injection. A variable NO_x reduction range of 38% to 88% represented expected NO_x reduction efficiency.^x Other tests conducted with sodium bicarbonate sorbent injection produced results which were only relative to ammonia usage. NO_x reduction with ammonia injection was in the range of 21% to 29%, while operation without ammonia injection produced most tests with no NO_x reduction. Test 009, which used copper oxide sorbent, did not provide any useful data regarding NO_x reduction.

A P P E N D I X 2F

4179

DRAWING LIST

(APPENDIX 2F)

DRAWING NUMBER

DRAWING SUBJECT

S9513/GA800

ENGINE TEST CELL (CYCLONE ALONE)

GA801

**ENGINE TEST CELL (ENVELOPE FILTER GRAVITY
FEED SORBENT)**

GA802

ENGINE TEST CELL (GRANULAR BED FILTER)

GA803

**ENGINE TEST CELL (CYCLONE AND GRANULAR BED
FILTER)**

GA804

ENGINE TEST CELL ERECTION DETAILS

GA805

**ENGINE TEST CELL (ENVELOPE FILTER, PNEUMATIC
FEED SORBENT)**

S9513/FC801

ENGINE TEST CELL DUCTWORK DETAILS

FC802

ENGINE TEST CELL DUCTWORK DETAILS

FC803

ENGINE TEST CELL DUCTWORK DETAILS

FC804

ENGINE TEST CELL DUCTWORK DETAILS

S9513/FA820

(HIGH TEMP) ENVELOPE FILTER ASSEMBLY

FA821

(HIGH TEMP) ENVELOPE CASING DETAILS

FA822

(HIGH TEMP) ENVELOPE CASING DETAILS

FA823

(HIGH TEMP) ENVELOPE INLET DETAILS

FA824

(HIGH TEMP) ENVELOPE AIR PIPING DETAILS

FA825

(HIGH TEMP) ENVELOPE OUTLET DETAILS

FA826

(HIGH TEMP) ENVELOPE TUBE SHEET DETAILS

FA827

(HIGH TEMP) ENVELOPE AIR PIPING DETAILS

FA828

(HIGH TEMP) ENVELOPE FILTER FRAME DETAILS

VIEW
PIPE SUPPORTS NOT SHOWN

PLAN

CAD FILE NO: 813CA800				
REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION
DESIGNED BY				
CHECKED BY				
APPROVED FOR DESIGN				
APPROVED FOR CONSTRUCTION				
APPROVAL DATE

<p align="center">GE Environmental Systems</p>			
<p align="center">ENGINE TEST CELL #2 CWS DIESEL ENGINE EMISSION CONTROL EQUIPMENT #6.5 JM199.539 CYCLONE</p>			
<p><small>THIS IS A PROPERTY OF A MEMBERSHIP COMPANY OF THE NATIONAL ASSOCIATION OF ENGINE TESTERS. IT IS TO BE USED FOR THE PURPOSES OF THE ASSOCIATION AND IS NOT TO BE LOANED, REPRODUCED, COPIED, OR IN ANY MANNER USED FOR ANY OTHER PURPOSE. IT IS TO BE RETURNED TO THE NATIONAL ASSOCIATION OF ENGINE TESTERS, 1000 N. 17TH AVENUE, DENVER, CO 80202, WHEN THE PROPERTY IS NO LONGER NEEDED FOR THE PURPOSES OF THE ASSOCIATION.</small></p>	<p align="center">UNITED FOR EX-100-1000</p>		<p align="center">DATE</p>
	<p align="center">APPROVED FOR USE</p>		<p align="center">APPROVED FOR USE</p>
	<p align="center">S9513</p>		<p align="center">GA-800</p>
<p align="center">SCALE - NONE</p>	<p align="center">IF</p>		<p align="center">0</p>

277 01 000 MF *RC*

CAD FILE NO. 8130A801

REVISION	DESCRIPTION	DESCRIPTION	REVISION
DESIGNED BY			
CHECKED BY			
APPROVED FOR DESIGN			
FOR CONSTRUCTION

7 SECTION

FOR BILL OF MATERIAL SEE A/BGA-1.

GE Environmental Systems

ENGINE TEST CELL #2
CWS DIESEL ENGINE
EMISSION CONTROL EQUIPMENT
ENVELOPE FILTER
GRAVITY FEED SORBENT/PRECOAT

	DESCRIPTION	DESCRIPTION	DESCRIPTION	1	DESCRIPTION	0	DESCRIPTION
				WIEBACH DESCHONG VANKLEUNEN	ADDED INDEX NUMBERS 8" DIET PIPE WAS 4"	WIEBACH DESCHONG VANKLEUNEN	DRAWN
					1/8/91		8/1/90

[illegible]

GE Environmental Systems			
ENGINE TEST CELL #2 CWS DIESEL ENGINE EMISSION CONTROL EQUIPMENT GRANULAR BED ARRGT.			
DATE	REASON FOR DISPOSITION	TIME	
APPROXIMATE OIL	EXHAUST NUMBER	REMARKS	
S9513	GA-802	0	

OUT 7 12 10 AM

SAP FILE NO: S130A803		DESCRIPTION		DESCRIPTION		DATE	
INITIALS							
ISSUED BY							
CHECKED BY							
REVIEWED FOR DESIGN							
APPROVED FOR CONSTRUCTION							
APPROVAL DATE

[illegible][illegible]

TYPICAL C
F
2" DIA. PIPE

CAD FILE NO. S13CAMP04				
REVISION	DESCRIPTION	DESCRIPTION		
DESIGN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
APPROVED FOR ENGINEERING				
APPROVAL DATE

GE Environmental Systems			
ENGINE TEST CELL #2 CWS DIESEL ENGINE EMISSION CONTROL EQUIPMENT			
ERECTION DETAILS			
DATE	ISSUED FOR ERECTION	BY	
APPROVED BY	DRAWN NUMBER	REVISED	
S9513	GA-804	0	
SCALE - NONE

VIEW

PLAN

CAD FILE NO: 5130A805

REVISION	DESCRIPTION	REVISION
DESIGNED BY		
CHECKED BY		
REVIEWED FOR DESIGN		
APPROVED FOR ENGINEERING		
APPROVAL DATE

SECTION

7. SECTION

1 SECTION

FOR BILL OF MATERIAL SEE A/BGA-1.

GE Environmental Systems

ENGINE TEST CELL #2
CWS DIESEL ENGINE
EMISSION CONTROL EQUIPMENT
ENVELOPE FILTER
PNEUMATIC FEED SORBENT/PRECOAT

	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
					WIEBACH DESHONG VANKLEUNEN	WIEBACH DESHONG VANKLEUNEN	DRAWN 8/1/90

[illegible]

8

7

6

CAD FILE NO. 513/CB01

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE			

[illegible]

SECTION
TYP. (4) SIDES

 DETAIL

SECTION
TYP. (4) PLACES

[illegible]

8

7

6

SECTION 1
803 SECTION 2
803 SECTION 3
803 SECTION 4
803

5/8" HX
4 1/2"
1 1/2"

DUCT
12 1/2 X 2
TYP. UNLESS
ALL MATERIAL

CADD FILE NO. 513/FC803		DESCRIPTION		DESCRIPTION	
DESIGN					
BY					
CHECKED BY					
REVIEWED FOR DESIGN					
APPROVED FOR ENGINEERING					
APPROVAL DATE

2 x 1/4
NOTED
BTM A-38

[illegible]

JA 10 1831

ITEM	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

GE Environmental Systems			
ENGINE TEST CELL #2			
CWS DIESEL ENGINE			
EMISSION CONTROL EQUIPMENT			
DUCTWORK SUPPORT DETAILS			
DATE	REVISION FOR TEST SECTION	BY	
APPROVED BY	DRAWN NUMBER	REVISION	
S9513	FC-804	0	
SCALE - NONE

CAD FILE NO: 513FA820

	DESCRIPTION	DESCRIPTION	DESCRIPTION
REVISION			
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

NOTES:

1. FABRICATION TO BE IN ACCORDANCE WITH SPECIFICATION NUMBER A/SXX-9.
2. FOR WELDING SPECIFICATION, SEE SPECIFICATION NUMBER A/XX-003.
3. ALL MATERIAL TO BE: ASTM A304 STAINLESS STEEL, UNLESS NOTED
4. ALL PLATE MATERIAL TO BE 3/16" THK., UNLESS NOTED
5. ALL PIPE TO BE ASTM A312 TP 304 SCH. 40S STAINLESS STEEL, UNLESS NOTED.
6. ALL THREADED PIPE FITTINGS TO BE ASTM A-182, GRADE F304 CLASS 3000 ANSI B16.11, UNLESS NOTED
7. ALL WELDED PIPE FITTINGS TO BE ASTM A-182, GRADE F304.
8. ALL FLANGES TO BE ASTM A-182 GRADE F304 150 LBS. RAISED FACE SLIP-ON.
9. NO PAINT REQUIRED.
10. FOR LIST OF REFERENCE DRAWINGS AND QUANTITIES SEE BILL OF MATERIAL A/BFA-2.
11. FOR INSTALLATION OF GASKET "23" SEE A/SFA-1.

DETAIL

TYPICAL ALL JOINTS

[illegible]

CAD FILE NO: 513FAB21		DESCRIPTION		DESCRIPTION		DESCRIPTION	
REVISION							
DRAWN BY							
CHECKED BY							
REVIEWED FOR DESIGN							
APPROVED FOR ENGINEERING							
APPROVAL DATE							

8

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5

1 SECTION
821

2 SECTION
821 TYPICAL CORNER

3 SECTION
821 NOTE TO FABRICATOR:
JOINT COULD BE BENT

3/1
3/1

4
82

A DETAIL
821

B VIEW
822

CAD FILE NO: 513FAB22

	DESCRIPTION	DESCRIPTION	DESCRIPTION
REVISION			
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE			

8

7

6

5

VIEW

INLET

VIEW

PERFORATED PLATE
11 GA. ASTM A304 SS
40% OPEN AREA
3/8" DIA. X 9/16"
STAGGERED C

1/8" V1-6

1" X 3/16" F.B.

1/8" V1-6

1/8" V1-2-9

1/8" V1-2-9

VIEW

CAD FILE NO: 513FAB23

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

NOTE:
FOR GENERAL NOTES SEE D/FA-820.

DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION

GE Environmental Systems			
ENVELOPE FILTER INLET DETAILS			
<small>NOTES</small> This is a preliminary drawing of a proposed design of a component or assembly. It is not to be used for construction or manufacturing without the approval of the design engineer. It is the responsibility of the user to verify the accuracy of the information and to obtain the necessary approvals before construction.		<small>ISSUES FOR CONSTRUCTION</small> DATE	
<small>AUTHORIZATION NO.</small> S9513		<small>DRAWING NUMBER</small> FA-823	
<small>SCALE</small> NONE		<small>REVISION</small> 0

CAD FILE NO: 513FA824

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE			

8

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5

6" 150# R.F.
S.O. FLANGEUNLESS
NOTED $\frac{3}{16}$
 $\frac{3}{16}$ SECTION
9
8251
825 VIEW3
8251
8251
825 2
8252
8253
8253
825 OUTLET 3
825 (28) 7/16" DIA.
HOLES

(12) 3/4" DIA. HOL

2
825 VIEW

CAD FILE NO: 513FA825

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE			

[illegible]

NOTE:
FOR GENERAL NOTES SEE D/FA-820.

Technical drawing of a circular plate. The drawing shows a cross-section of a plate with a central hole. The outer diameter is labeled as 11" O.D. and the inner diameter is labeled as 8" I.D. The plate is labeled as 3/16" PLATE. There are eight small circles, likely representing rivets or bolts, arranged in a circular pattern around the central hole. A dimension line indicates a distance of 8" I.D. from the center to the edge of the inner hole.

Technical drawing of a rectangular plate with dimensions and hole locations. The plate has a total width of 1'-5" and a total height of 1'-1". The drawing shows a central rectangular area with a dashed line indicating a hole. The distance from the left edge to the center of the hole is 1'-5". The distance from the right edge to the center of the hole is 1'-1". The distance from the top edge to the center of the hole is 1'-1". The distance from the bottom edge to the center of the hole is 1'-1". The distance from the left edge to the center of the hole is 1'-5". The distance from the right edge to the center of the hole is 1'-1". The distance from the top edge to the center of the hole is 1'-1". The distance from the bottom edge to the center of the hole is 1'-1".

TRANSITION

Diagram showing the elevation view of a bent plate. The plate has a horizontal section of 1/8" and a vertical section of 1/2". The total length of the horizontal section is 1 1/8". The plate is bent at a 90-degree angle. A section line is shown with the label "SECTION 5" and the number "825" in a circle.

Technical drawing of a turning vane assembly. The drawing shows a side view of a vane with a curved leading edge and a flat trailing edge. Key dimensions and labels include:

- FLANGE "A"**: Located at the top left of the vane.
- FLANGE "B"**: Located at the bottom left of the vane.
- TURNING VANE**: The main component being detailed.
- 1/2" PIPE COUPLING WELDED OVER 3/4" DIA. HOLE IN 3/16" PLATE**: A detail note pointing to a hole in the trailing edge.
- 3" R**: Radius of the curved leading edge.
- 1'-11 13/16"**: Total length of the vane.
- 10 8/16"**: Distance from the top flange to the start of the curve.
- 1'-1 1/4"**: Distance from the bottom flange to the start of the curve.
- 2"**: Thickness of the vane at the trailing edge.
- 8"**: Distance from the trailing edge to the center of the coupling.
- 1'-1 3/4"**: Distance from the trailing edge to the end of the vane.
- 5**: Dimension at the top of the vane.
- 8**: Dimension at the bottom of the vane.
- 8/25**: Fractional dimensions at the top and bottom of the vane.

FLANGE

8 3/4"

1 1/2"

1"

DETAIL C B25

Diagram of a diamond-shaped duct with a curved internal wall. The duct has a top width of $6R$ and a bottom width of $3/16$. The internal wall is curved, and the duct is labeled "VANE TO DUCT TYPE BOTH SIDES".

VIEW

Technical drawing of a mechanical assembly, likely a pump or motor component. The drawing shows a cross-section of a cylindrical body with a conical section on the right. Dimensions and callouts are as follows:

- Overall length: 15
- Internal diameter (left): $\frac{825}{10}$
- Internal diameter (right): $\frac{825}{7}$
- External diameter (right): $\frac{825}{9}$

SECTION 10

Diagram of a Tee fitting. A horizontal line with a circle at its right end is labeled $1/8$. This line connects to a vertical line. A horizontal line branches off to the right from the vertical line. A label $1/4$ PLATE points to the vertical line. A label $1/8$ PIPE points to the horizontal branch.

Edid

1
826 SECTION

2
826 SECTION
TYP. BOTH ENDS

A
826 DETAIL

A
826

A
826

C1 X 1/2 X 1/8

1 1/2"

10"

10 1/8"

10"

1 1/2"

TYP.

G

CAD FILE NO: S13FAB26

REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION
DRAWN BY					
CHECKED BY					
REVIEWED FOR DESIGN					
APPROVED FOR ENGINEERING					
APPROVAL DATE

TUBE SHEET DETAIL

NOTE:

1. FOR GENERAL NOTES SEE D/FA-820.

GE Environmental Systems			
ENVELOPE FILTER TUBE SHEET DETAILS			
<small>THIS IS A REPRESENTATION OF A WORKING DRAWING OF A DESIGN. IT IS NOT TO BE USED FOR CONSTRUCTION OR FOR ANY OTHER PURPOSE WITHOUT THE WRITTEN AUTHORIZATION OF THE DESIGNER. IT IS THE RESPONSIBILITY OF THE USER TO OBTAIN THE NECESSARY INFORMATION TO CONSTRUCT OR OPERATE THE EQUIPMENT SHOWN HEREIN. THE USER SHALL BE RESPONSIBLE FOR ANY ERRORS OR OMISSIONS IN THIS DRAWING. THE USER SHALL BE RESPONSIBLE FOR ANY CHANGES TO THIS DRAWING. THE USER SHALL BE RESPONSIBLE FOR ANY DAMAGE TO THE EQUIPMENT SHOWN HEREIN. THE USER SHALL BE RESPONSIBLE FOR ANY LOSS OF DATA OR INFORMATION. THE USER SHALL BE RESPONSIBLE FOR ANY OTHER CONSEQUENCES OF THE USE OF THIS DRAWING.</small>	AUTHORIZATION NO. S9513	DRAWING NUMBER FA-826	DATE 0
SCALE- NONE	DRAWN 12/17/90		

DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION

8

7

6

5

DRILLED HOLES TO BE FREE FROM BURRS
ON THE INSIDE & OUTSIDE OF PIPE.
REMOVE ALL LOOSE DRILL TURNINGS,
TAILINGS & CHIPS FROM INSIDE THE
PIPE. ALL HOLES MUST ALIGN VERTI-
CALLY WITH MAXIMUM ALLOWABLE
TOLERANCE AT $\pm 2^\circ$ ANGULAR ROTATION
OFF VERTICAL CENTERLINE.

TRUE
VERTICAL3
827 SECTION

L1 1/2 X 1 1/2 X 1/8 X 1 1/2 LG.

A
827 DETAIL3/4" SCH. 40 PIPE
X 2" LG. T.O.E.
(ASTM A-120)

41 AIR PIPE

3/4" SCH. 40 PIPE
X 2" LG. T.O.E.
(ASTM A-120)

49 AIR PIPE

3/4" SCH. 40 PIPE
X 1'-0 1/2" LG. T.O.E.

42 AIR PIPE

3/4" SCH. 40 PIPE
X 1'-1 1/2" LG. T.O.E.

43 AIR PIPE

1/8" MAXIMUM ALLOWABLE SWEEP
EITHER SIDE OF CENTERLINE2
827 VIEWA
827

44 AIR PIPE

CAD FILE NO: 513FAB27

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

5 of 7

5 FILTER FRAME

NOTE:
1. FOR GENERAL NOTES SEE D/FA-820

GE Environmental Systems			
ENVELOPE FILTER FILTER FRAME DETAILS			
NOTICE THIS IS A REPRODUCTION OF A COMPUTER GENERATED DRAWING OF A GE ENVIRONMENTAL SYSTEMS, INC. AND IS SUPPLIED FOR USE ONLY FOR THE PROJECT AND SITE SHOWN. IT IS THE PROPERTY OF GE ENVIRONMENTAL SYSTEMS, INC. AND SHALL NOT BE REPRODUCED, COPIED, OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPYING, RECORDING, OR BY ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM, WITHOUT THE WRITTEN PERMISSION OF GE ENVIRONMENTAL SYSTEMS, INC.		ISSUED FOR CONSTRUCTION	
AUTHORIZATION NO. S9513		DRAWING NUMBER FA-828	
SCALE- NONE		REVISION 0	

DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION

0
 WEIERBACH
 P.D. Shing
 R. J. Miller
 DRAWN
 12/27/90

TABLE 2F-1
SUMMARY OF HOT GAS ENVELOPE FILTER TEST CONDITIONS AND RESULTS
CHAPTER 2F
FILE SC2FD1

TEST SERIES	HOT 002	HOT 003	HOT 004	HOT 005	HOT 006
TEST NUMBER	1/23/92	1/24/92	2/25/92	2/26/92	3/24/92
TEST DATE	NEUTRALITE	NEUTRALITE	NEUTRALITE	NEUTRALITE	NEUTRALITE
PRE-TEST PRECOAT MATERIAL	300	300	300	300	300
PRE-TEST PRECOAT AMOUNT, GRAMS	580	<280	660	<445	<440
GAS FLOW, ACFM, START	450	-	-	-	-
GAS FLOW, ACFM, OTHER	290	280	430	445	440
GAS FLOW, ACFM, END	ALUMINA	SODIUM BICARBONATE	ALUMINA	COPPER SULFATE	SODIUM BICARBONATE
SORBENT/PRECOAT MATERIAL	0, 4	0, 4	NONE	4.5, 2.5	0, 2.0
AMMONIA INJECTION, STANDARD L/MINUTE	-	550	-	580 TO 800	630 TO 830
FILTER INLET TEMPERATURE, F.	5	0.7	5	5	.7
SORBENT/PRECOAT CONCENTRATION, GRAINS/ACF	.25	.25	.25	.25	.25
ASSUME FILTER INLET CWS ASH, GRAINS/ACF	53.307	-	-	-	-
COMPOSITE FILTER INLET, LBS.	.0673	.0216	.0591	.0608	.0362
COMPOSITE FILTER OUTLET CONCENTRATION, GRAINS/ACF	.4982	-	-	-	-
COMPOSITE FILTER OUTLET, LBS.	99.07	97.73	98.87	98.8	96.1
COMPOSITE PARTICULATE COLLECTION EFFICIENCY, %	1, 2, 3(OFF), 4, 5,	NONE	1(OFF), 2, 3, 4	1, 2, 3	1, 2, 3, 4
CLEANING EVENT, NUMBER	6(OFF), 7, 8, 9	-	-	-	-
(SAME, CONTINUED)	17.0, 14.5, 14.3, 15.8, 10.8	7.6(MAXIMUM)	22, 9, 9, 12	15, 13.5, 12	9, 12.5, 11.5, 13.5
CLEANING EVENT INITIATION, IWG	10.0, 7.5, 7.2, 9.5	-	-	-	-
(SAME, CONTINUED)	12.8, 14.3*, 5.0, 10.0, 10.0*	-	1(<ACFM), 2, 5, 9.5	3.5, 4.5, 4.5	4.0, 4.5, 9*, 6
CLEANING EVENT CLEANDOWN, IWG	5.0, 6.5*, 7.0*, 8.0*	-	-	-	-
(SAME, CONTINUED)	-	-	-	0	190%
SORBENT STOICHIOMETRY, %	-	-	-	208%, 111%	0%, 99%
AMMONIA STOICHIOMETRY, %	-	320	250 TO 380	-	230 TO 320
FILTER INLET SO2, PPMV	-	-	-	-	0 TO 50
FILTER OUTLET SO2 (WITH SORBENT), PPMV	-	-	-	-	100% TO 84%
SO2 REDUCTION (WITH SORBENT), %	-	920	880	400	360 TO 400
FILTER INLET NOX, PPMV	-	-	-	250 TO 50	300
FILTER OUTLET NOX (WITH AMMONIA), PPMV	-	-	-	38% TO 88%	21%
NOX REDUCTION (WITH AMMONIA), %	-	-	-	-	-

NOTE:
ALL CLEANING OF FILTER MEDIA WAS PERFORMED AS A SINGLE ONLINE EVENT EXCEPT AS NOTED (OFF) FOR OFFLINE CLEANING OR (CONT) FOR CONTINUOUS CLEANING

* TABLE 2F-1A *

HOT 007 3/25/92 NEUTRALITE 300 <430 430 530 SODIUM BICARBONATE 0, 2.0, 4.0 630 TO 800 0, 0.7, 1.0 .25 15.628 .0349 .4937 96.8 1, 2, 3 - 11.5, 13.8, 16 - 3.5, 5.5, 9.5/3* - 0% TO 295% 0% 180%, 90% ASSUME 270 20 TO 90 93% TO 67% 380 270 TO 290 29% TO 24%	HOT 009 8/25/92 NEUTRALITE 300 <430 - 430 COPPER OXIDE 0, 2.0 460 TO 730 3, 10, 0 (x10%) .25 20.89 .0865 .5486 97.4 1, 2, 3, 4, 5, 6 10.5, 10.5, 10.5, 11.5, 16, 19.7 3.5, 4.5, 6.5, 10*, 14.5*, 13.7* 148%, 512%, 0% 0%, 81% 200 0 TO 1100? ? 450 0 TO 450? ?	HOT 008 3/26/92 NEUTRALITE 300 <510 - 510 ALUMINA NONE 630 TO 720 .76 .25 - .0398 - 96.06 1, 2 - 11.2, 14.8 - 4.5, 13.0* - 0% 0% - - - - -	HOT 010 8/26/92 NEUTRALITE 300 <450 - 450 SODIUM BICARBONATE 0, 2.0 470 TO 770 1.4, 4.74 .25 27.959 .049 .4338 98.45 1, 2, 3, 4(CONT), 5(OFF) 14.5, 14.0 5.5, 8.5*, 11.7*, 14.0*, 5.9 270%, 914% 0%, 85% 300 TO 400 20 93% TO 95% 400 TO 420 320 22%	HOT 011 8/27/92 NEUTRALITE 300 <540 - 540 SODIUM BICARBONATE 0, 2.0 520 TO 750 0.45, 4.46 .25 23.653 - - 1, 2, 3(OFF), 4, 5(OFF), 6, 7, 8(OFF), 9(CONT) 10.4, 12.0, 12.9, 11.5, 16.0, 11.3, 10.8, 13.1, 6.1 6.1, 12.6*, 5.7, 12.6*, 6.1, 9.9*, 11.2*, 6.1, 12.0* 98%, 966% 0%, 48% 300 TO 320 20 TO 100 93% TO 70% 540 TO 670 430 29%
--	--	---	---	--

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 002

* FIGURE 2F-1 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 002

* FIGURE 2F-2 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 002

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 002

* FIGURE 2F-4 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 003

* FIGURE 2F-5 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 003

* FIGURE 2F-6 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 003

— CO, PPMV
— NOX, PPMV
— HC, PPMV
— SO₂, PPMV

* FIGURE 2F-7 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 003

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 004

* FIGURE 2F-9 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 004

* FIGURE 2F-10 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 004

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 004

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 005

* FIGURE 2F-13 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 005

* FIGURE 2F-14 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 005

* FIGURE 2F-15 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 005

— CO, PPMV
— NOX, PPMV
— HC, PPMV

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 005

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 006

* FIGURE 2F-18 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 006

* FIGURE 2F-19 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 006

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 006

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 006

NH₃, L/MIN.
O₂, %VOLUME
CO₂, %VOLUME

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 007

* FIGURE 2F-23 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 007

* FIGURE 2F-24 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 007

* FIGURE 2F-25 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 007

— CO, PPMV
 — NOX, PPMV
 — HC, PPMV
 - - - SO2, PPMV

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 007

* FIGURE 2F-27 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 009

* FIGURE 2F-28 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 009

* FIGURE 2F-29 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 009

 * FIGURE 2F-30 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 009

— CO, PPMV
 — NOX, PPMV
 — HC, PPMV
 — SO2, PPMV

 * FIGURE 2F-31 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 009

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 009

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 008

* FIGURE 2F-34 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 008

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 010

* FIGURE 2F-36 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513
500 ACFM HOT GAS ENVEL. FILTER TEST 010

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 010

 * FIGURE 2F-38 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 010

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 010

— NH₃, L./MIN.
 — O₂, %VOLUME
 — CO₂, %VOLUME

 * FIGURE 2F-40 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 011

* FIGURE 2F-41 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 011

* FIGURE 2F-42 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 011

 * FIGURE 2F-43 *

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 011

DOE/GETS COAL FUEL DIESEL PROJECT S9513

500 ACFM HOT GAS ENVEL. FILTER TEST 011

TAB 8

CHAPTER 26

Commensurate with Task 2, Emissions Applied R&D

Task 2.2.3, 2.2.4, & 2.2.5
Sorbent Regeneration

Introduction

A reason for the selection of copper oxide as a sorbent for process study was the ability to remove SO_2 , as well as simultaneous removal of NO_x by the addition of ammonia. However, copper oxide sorbent cannot be treated as throwaway, but must be recycled for economic reuse. There are two requirements for the regeneration of reacted copper oxide sorbent. CWS fuel ash contamination must be removed from the sorbent material. This was the reason for the concern of the particle size of the sorbent relative to the ash particulate. The greater the difference of the particle size of these two materials, the easier and more efficient the separation can be performed. The other regeneration requirement is the conversion of copper sulfate reacted sorbent back to copper oxide reactivated sorbent. This process can be accomplished by high temperature (1200 F) thermal decomposition, or by reduction using Methane at elevated temperature (900 F), in accordance with the following reaction equations:

Thermal decomposition:

Methane reduction:

**DOE/GETS TOPICAL REPORT
CHAPTER 2G**

Consultant Research

A research project was contracted to Professor Gabriel Tardos, Department of Chemical Engineering, The City College of New York, to determine the feasibility of separation of coarse sorbent particulate and ash particulate, using an elutriation process. The report of this research is enclosed in Appendix 2G. Actual testing of this requirement was performed using a mixture of coarse alumina and fine silica powders. The two components of the mixture supplied by GEESI were the same constituent materials used by GEESI cold flow Emissions Control concept testing.

Aside from some ambiguity caused by different and conflicting methods of particle size analysis, the program did conclude that the two powders could be separated at ambient temperature operation, as well as at 400 C operation. A separation which removed 50% to 70% of the fine powder simulating CWS ash was obtained at a fluidization velocity of 8 to 10 cm/sec (16 to 20 FPM) at 400 C operation by an elutriation time of approximately 50 minutes with negligible loss of coarse particulate representing sorbent material.

GEESI Bench Scale Testing Facility

A bench scale test facility was cold flow tested at GEESI laboratory to study a composite process to perform removal of fine CWS ash and to simulate fluidized bed regeneration of the sorbent. The bench scale test facility is illustrated by Figure 2G-1 in Appendix 2G. The following is an explanation of the operation of this test facility.

Feed material consisting of reacted sorbent and CWS ash is fed into the high velocity riser of a spouted bed, and is discharged into a lower velocity elutriation chamber where fine particulate is removed and collected in a "spouted bed fines filter". Larger particulate settles in the elutriation chamber and is free to reenter the spouted bed riser and recirculate to the elutriation chamber. When a sufficient amount of large particulate material accumulates in the elutriation chamber, all gas flow becomes directed up the riser for removal of fines. When the equilibrium level of accumulated large particulate reaches an overflow, the large particulate sorbent material, from which the ash particulate has been removed, discharges through a submerged inlet to a fluidized bed. The fluidized bed represents the regeneration process for the sorbent. This process also provides a second stage opportunity for removal of additional fine particulate ash, which is collected in a "fluidized bed fines filter". When the equilibrium fluidized bed depth reaches an overflow, cleaned and regenerated sorbent is discharged to a "product reservoir".

**DOE/GETS TOPICAL REPORT
CHAPTER 2G**

The intention of the design of the composite fines removal and sorbent regeneration system was to utilize the same gas for both fines removal and sorbent regeneration. In this manner, the fluidized bed would be located in the plenum below the spouted bed riser, with any fines which were removed by the second stage fluidized bed entering the spouted bed riser along with the spouted bed gas flow. However, at this experimental stage of the program, it was not practical to iterate experiments of spouted bed and fluidized bed operating velocity and component dimensions which would permit simultaneous operation of both beds using the same gas flow. Therefore, an experimental expediency was to create two separate gas flow systems which would permit experimentation of each gas flow operation without affecting the other process.

Discussion of Test Results

Results of three bench scale tests are summarized in Table 2G-1. Test operating conditions of elutriation chamber and fluidized bed velocities were in the range between 16 and 28 FPM. This range was commensurate with the room temperature operating range 1 to 30 cm/sec (2 to 59 FPM) determined by the research of Professor Tardos, as appropriate for separation of fine and coarse particulate.

Tests 1 and 2 used as feed material a simulation of an expected off-product mixture of reacted sorbent and CWS ash consisting of alumina (52 micron MMD) and silica powder (3.7 micron MMD) in a mixture ratio of 5:0.2, which simulates the expected use of sorbent/precoat material and expected CWS ash expressed as grains/ACF of each constituent. A particle size distribution of a prepared mixture of test particulate had a reasonable value of 48 micron MMD for Test 1, but a suspect value of 42 micron MMD for Test 2.

Test 1 produced a total fines removal of 6.3% of the feed material, as contrasted with only 3.85% of the total feed material consisting of simulated fine ash particulate. However, an additional amount of fine particulate was also contributed by fine particulate contained in the alumina, in the amount of approximately 2% of the total alumina finer than 3.7 microns. If all of the total removed "fines" consisted of only objectionable fine particulate, the resulting sorbent product particle size would have been even coarser than the starting 52 micron MMD. However, the actual resulting sorbent product was only 49 micron MMD and was only slightly coarser than the starting feed material. Therefore, it must be concluded that the total "fines" removed consisted of material other than only the objectionable simulated ash particulate. The validity of the particle size results of Test 1 is illustrated by a reconstruction of all test fractions at the 48 micron MMD particle size of the starting feed material. This reconstruction verification produced a value of 49.2%, which is in good agreement with the theoretical 50% value for the MMD.

DOE/GETS TOPICAL REPORT CHAPTER 26

Test 2 was planned to be performed with the same feed mixture of alumina and silica to simulate sorbent/precoat and CWS ash, as was used for Test 1. However, a particle size analysis of the feed material indicated a finer 42 micron MMD. Test 2 was performed at reduced air flow operating conditions, relative to the operating conditions for Test 1. It is significant that the sorbent product MMD was 47 microns, as compared to 49 microns for Test 1. Therefore, if the same feed material was used and if the air flow was reduced, the amount of "fines" removed should be less than obtained for Test 1. However, the amount of "fines" was much greater than obtained by Test 1, and it must be concluded that the feed for Test 2 was truly finer than the feed used for Test 1. When the test fractions were reconstructed at the 42 micron MMD of the feed material, the result was 57.5% > 42 microns. This result is a significant contradiction with the theoretical 50%. However, if the feed MMD is assumed to be 44-45 microns, the reconstruction verifies 50% larger. Therefore, the test operating conditions of reduced air flow and finer feed material resulted in a failure to achieve the 52 micron MMD of the original sorbent, and lost more sorbent particulate with the removed "fines".

Test 3 duplicated the air flow operating conditions of Test 1, but used a different feed material consisting of a larger proportion of fine material simulating CWS ash. For this test, the fine material consisted of coal fuel fly ash with a larger particle size of 15 micron MMD. A particle size analysis of 57 micron MMD verified the use of the coarser ash constituent. Therefore, the air flow operating condition would be expected to remove less "fines", and the test results indicated that this did occur.

The results of these bench scale tests are inconclusive. Because of the small size of the test facility, it was difficult to control feed material feed rate and to achieve equilibrium operation of the transfer of particulate between the two stages of elutriation. Further improved test facility logistics was planned, but was not performed.

Pilot Scale Sorbent Regeneration Facility

A pilot scale sorbent regeneration facility was designed to support operation of the 500 ACFM hot gas Envelope Filter. The design of this facility is illustrated by GEESI design Drawings S9513/FA870 through FA874, which are enclosed in Appendix 2G. The planned purpose of this facility was to investigate the effect of repeated regeneration and reuse of copper oxide/alumina sorbent upon Envelope Filter SO₂ and NO_x reduction, as well as filter cleanability performance.

The pilot regeneration facility was designed as a batch fluidized bed operation to simultaneously remove fine ash particulate and to regenerate reacted copper sulfate back to copper oxide. This test facility operation was a simplification of the function described by the composite bench scale test facility.

**DOE/GETS TOPICAL REPORT
CHAPTER 26**

The pilot facility was planned to operate by thermal decomposition using 1200°F air as the fluidizing medium and to operate at a fluidizing velocity of approximately 28 FPM based upon the bench scale cold flow test facility. Removal of "fines" was planned to be collected in a Candle Filter assembly containing 10 - 2 inch diameter metal fiber filter media candle filters. This filter is described by GEESI drawings S9513/FA850 through 854 which are enclosed in Appendix 26. This filter was designed to operate at high temperature with reverse air pulse cleaning and had been designed to support other program research performed at GE CRD. Planned operation of the pilot facility to neutralize SO₂ off gas was to bubble the off gas through a sorbent solution.

A failure of the program to develop a vendor source of copper oxide/alumina sorbent in preparation for the 500 ACFM hot gas Envelope Filter testing prevented the use of the pilot sorbent regeneration facility to investigate sorbent regeneration and reuse.

A P P E N D I X 26

111

DRAWING LIST

(APPENDIX 28)

DRAWING NUMBER

DRAWING SUBJECT

S9513/FA870

SORBENT REGENERATOR ASSEMBLY

FA871

SORBENT REGENERATOR DETAILS

FA872

SORBENT REGENERATOR DETAILS

FA873

SORBENT REGENERATOR DETAILS

FA874

SORBENT REGENERATOR SUPPORT SKID

FA875

**SORBENT REGENERATOR SUPPORT POROUS PLATE
ASSEMBLY**

S9513/FA850

CANDLE FILTER ASSEMBLY

FA851

CANDLE FILTER DETAILS

FA852

CANDLE FILTER DETAILS

FA853

CANDLE FILTER DETAILS

FA854

CANDLE FILTER DETAILS

CND FILE NO. S13FAB70		DESCRIPTION		DESCRIPTION		DATE	
DESIGNED BY							
CHECKED BY							
REVIEWED FOR DESIGN							
APPROVED FOR ENGINEERING							
APPROVAL DATE

1. FABRICATION TO BE IN ACCORDANCE WITH SPECIFICATION NUMBER A/3XX-B.
2. FOR WELDING SPECIFICATION, SEE SPECIFICATION NUMBER A/XX-003.
3. ALL PLATE MATERIAL TO BE ASME SA-240 316 STAINLESS STEEL UNLESS NOTED. CARBON MUST BE .04% OR HIGHER.
4. ALL PIPE FITTINGS TO BE ASME SA-182, 316 WP, THREADED, CLASS 3000. ANSI B16.11 UNLESS NOTED. CARBON MUST BE .04% OR HIGHER.
5. ALL PIPE TO BE ASME SA-312 1F316 SCH. 40S UNLESS NOTED. CARBON MUST BE .04% OR HIGHER.
6. ALL FLANGES TO BE ASME SA-182 F316. CARBON MUST BE .04% OR HIGHER.
7. NO PAINT REQUIRED.
8. FOR LIST OF REFERENCE DRAWINGS AND QUANTITIES SEE BILL OF MATERIAL A/BFA-30.

<h1 style="text-align: center;">GE Environmental Systems</h1>			
<h2 style="margin: 0;">CANDLE FILTER REGENERATOR ASSEMBLY</h2>			
<p>NAME</p> <p>THIS IS A REPRESENTATIVE OF THE MANUFACTURER, DESIGNER, OR INSTALLER OF THE EQUIPMENT. HE MUST BE FAMILIAR WITH THE EQUIPMENT, AND MUST BE ABLE TO PROVIDE THE FOLLOWING INFORMATION:</p> <p>1. NAME OF THE MANUFACTURER, DESIGNER, OR INSTALLER</p> <p>2. ADDRESS OF THE MANUFACTURER, DESIGNER, OR INSTALLER</p> <p>3. PHONE NUMBER OF THE MANUFACTURER, DESIGNER, OR INSTALLER</p> <p>4. NAME OF THE EQUIPMENT</p> <p>5. SERIAL NUMBER OF THE EQUIPMENT</p> <p>6. DATE OF INSTALLATION</p> <p>7. DATE OF INSPECTION</p> <p>8. NAME OF THE INSPECTOR</p> <p>9. ADDRESS OF THE INSPECTOR</p> <p>10. PHONE NUMBER OF THE INSPECTOR</p>		<p>MODELS FOR REGISTRATION</p> <p>BOX</p>	
<p>MANUFACTURER'S FILE</p> <p>DRAWING NUMBER</p> <p>VERSION</p>		<p>SCALE</p> <p>NONE</p>	

PLOT 1-8

REC'D 1032 MF 21

CAD FILE NO: 313FAS71				
DESIGNED BY		DESCRIPTION		DESCRIPTION
CHECKED BY				
APPROVED FOR DESIGN				
APPROVED FOR CONSTRUCTION				
APPROVAL DATE

TYPICAL CONNECTION
OF 1/4" PIPE TO
VESSEL

NOTES:
FOR GENERAL NOTES SEE E/FA-870.

<h1 style="text-align: center;">GE Environmental Systems</h1>			
<h2>CANDLE FILTER REGENERATOR DETAILS</h2>			
<p>NAME</p> <p>THIS IS A SPECIFICATION for a regenerable filter of the "Candle Filter" type, used for the removal of suspended solids and other contaminants from water. The filter is designed to be used in a continuous flow system and is capable of being regenerated in place.</p> <p>The filter consists of a cylindrical housing containing a number of pleated filter elements. The elements are made of a synthetic material and are designed to filter out particles of all sizes down to 10 microns. The filter is capable of handling a flow rate of up to 100 gpm and is designed to last for a minimum of 10,000 cycles.</p> <p>The filter is designed to be used in a continuous flow system and is capable of being regenerated in place. The regeneration process is controlled by a timer and a backwash valve. The filter is designed to be used in a continuous flow system and is capable of being regenerated in place.</p>	<p>DETAILS FOR CONSTRUCTION</p>	<p>SIZE</p>	
	<p>APPROXIMATE NO.</p>	<p>SHOWED NUMBER</p>	<p>APPROX.</p>
SCALE - NONE	S9513	FA-871	0

PLAY 1-4

JA: 23 DEC 1961

411.

CAD FILE NO. 513FAB72				
REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DATE
DESIGN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
APPROVED FOR ENGINEERING				
APPROVAL DATE

FOR GENERAL NOTES SEE E/FA-870.

[illegible]

PLOT 1-4

JAN 23 1962 MF RD

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6

VIEW

INLET PLENUM

CAD FILE NO. S13FA873

REVISION	DESCRIPTION	DESCRIPTION	DATE
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE			

5

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1

SECTION 1

873

2 SUPPORT LEG

873

SECTION 3

873

SECTION 4

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SECTION 5

873

SECTION 6

873

NOTE:
FOR GENERAL NOTES SEE E/FA-870

GE Environmental Systems			
CANDLE FILTER REGENERATOR DETAILS			
DATE	DESIGNED BY	CHECKED BY	APPROVED BY
5-1/15/92	W. H. HARRIS	W. H. HARRIS	W. H. HARRIS
AUTHORIZATION NO.		DATE OF REVISION	REVISION
S9513		FA-873	0
SCALE - NONE			
PLOT 1-4			

REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION	DATE	DESCRIPTION
1		2		3		4		5-1/15/92	W. H. HARRIS
5		6		7		8			
9		10		11		12			
13		14		15		16			
17		18		19		20			
21		22		23		24			
25		26		27		28			
29		30		31		32			
33		34		35		36			
37		38		39		40			
41		42		43		44			
45		46		47		48			
49		50		51		52			
53		54		55		56			
57		58		59		60			
61		62		63		64			
65		66		67		68			
69		70		71		72			
73		74		75		76			
77		78		79		80			
81		82		83		84			
85		86		87		88			
89		90		91		92			
93		94		95		96			
97		98		99		100			

4/5

BOY

CMB FILE NO. 513/AB71					
REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION
DESIGNED BY					
CHECKED BY					
REVIEWED FOR DESIGN					
APPROVED FOR ENGINEERING					
APPROVAL DATE

7/8" DIA. X 3 3/4" LG.
MACHINE BOLT
(BY GEESH RAD)

CHG FILE NO. 513FA875

REVISION	DESCRIPTION	DESCRIPTION	REVISION
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVED DATE

(CAD FILE NO: 513FAB50)

REVISION	DESCRIPTION	DESCRIPTION	DATE
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
REVIEWED FOR ENGINEERING			
PROJECT MANAGER APPROVAL			
APPROVAL DATE			
DRAWN/FILED

FLANGE "A"

- NOTES:
1. FABRICATION TO BE IN ACCORDANCE WITH SPECIFICATION NUMBER A/SIX-5.
2. FOR WELDING SPECIFICATION, SEE SPECIFICATION NUMBER A/XX-003.
3. ALL MATERIAL TO BE ASTM A304 STAINLESS STEEL UNLESS NOTED.
4. ALL PIPE FITTINGS TO BE ASTM A-182, GRADE F304, THREADED, CLASS 3000, ANSI B16.11 UNLESS NOTED.
5. ALL PIPE TO BE ASTM A312 TP304 SCH. 40S UNLESS NOTED.
6. ALL FLANGES TO BE ASTM A-182 GRADE F304 150 LBS. RAISED FACE SLP-ON.
7. NO PAINT REQUIRED.
8. A PRESSURE TEST SHALL BE CONDUCTED ON THE PIPING ASSEMBLY AS SHOWN ON PA-862 AFTER INSTALLATION IN 12 INCH DIAMETER CASING BUT BEFORE ATTACHING HOPPER. THE ASSEMBLY SHALL BE PRESSURIZED TO 10 LBS. PER SQUARE INCH AND MAINTAIN THIS PRESSURE FOR 30 MINUTES WITH A DROP IN PRESSURE. IF A DROP IN PRESSURE IS DETECTED IT IS A FAILURE.
9. FOR LIST OF REFERENCE DRAWINGS AND QUANTITIES SEE BILL OF MATERIAL A/BFA-15.

GE Environmental Systems

CANDLE FILTER COLLECTOR ASSEMBLY

NAME	DESIGN FOR CONSTRUCTION	DATE

AUTHORIZATION NO.	ISSUED NUMBER	REVISED
S9513	FA-850	0

SCALE -
NONE
IF

REF: 725 27 PL

421

PLAN

1 CASING

CAD FILE NO: 513FA851

REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION
DRAWN BY							
CHECKED BY							
REVIEWED FOR DESIGN							
REVIEWED FOR ENGINEERING							
PROJECT MANAGER APPROVAL							
APPROVAL DATE:							
MICROFILMED:							

MAY 31 1930 M.F. RO

CAD FILE NO: 513FA852

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR ENGINEERING				
PROJECT MANAGER APPROVAL				
APPROVAL DATE:				
MICROFILMED:

B
852
DETAIL
TYP. (4) LEGS

A
803
DETAIL

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852
SECTION

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SECTION
TYP. (4) LEGS

NOTE:
FOR GENERAL NOTES AND SPECIFICATIONS SEE DRAWING D/FA-850.

GE Environmental Systems		
CANDLE FILTER DETAILS		
NOTICE	ISSUES FOR CONSTRUCTION	DATE
<small>THIS IS A REPRESENTATIVE OF A DRAWING OF A GEORGE ELECTRIC ENGINEERING SERVICE, INC. AND IS SUBJECT TO THE POLICY OF THE COMPANY CONSTRUCTION, PRODUCTION, INFORMATION OF GEORGE ELECTRIC ENGINEERING SERVICE, INC. AND SHALL NOT BE REPRODUCED, COPIED OR REPRODUCED IN ANY MANNER WITHOUT THE WRITTEN PERMISSION OF GEORGE ELECTRIC ENGINEERING SERVICE, INC. NO PART OF THIS DRAWING IS TO BE USED FOR CONSTRUCTION OR FOR CONSTRUCTION OF ANY OTHER DRAWING.</small>	AUTHORIZATION NO.	DRAWING NUMBER
SCALE— NONE	S9513	FA-852
		REVISION
		0

DESCRIPTION	DESCRIPTION	U	DESCRIPTION
		AWW	
		DER	
		HT 5116190	
		ME 5116190	
			DRAWN
			4/9/90

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DETAIL

TRUE VERTICAL

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SECTION

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CAD FILE NO: 513FA853

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
REVIEWED FOR ENGINEERING				
PROJECT MANAGER APPROVAL				
APPROVAL DATE:				
MICROFILMED:

5 COMPRESSED AIR TANK

CAD FILE NO: 513FA854

REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION
DRAWN BY							
CHECKED BY							
REVIEWED FOR DESIGN							
REVIEWED FOR ENGINEERING							
PROJECT MANAGER APPROVAL							
APPROVAL DATE:							
MICROFILMED:

NOTE:

1. ALL PLATE AND STRUCTURAL SHAPES TO BE ASTM A-36.
2. FOR GENERAL NOTES AND SPECIFICATIONS SEE DRAWING E/FA-850.

GE Environmental Systems

CANDLE FILTER
DETAILS

DESCRIPTION	DESCRIPTION	O	DESCRIPTION
		AWW	
		DER	
		4/5/90	
		4/5/90	

PURPOSE This is a statement of a specific phase of research, listing the facilities, services, and is provided for use only for the purposes and for the purpose of the research and of the Government, and for the purpose of of the
--

11/90 11/90

TABLE 2G-1
SUMMARY OF BENCH SCALE COLD FLOW SORBENT REGENERATION TEST OPERATING CONDITIONS AND TEST RESULTS
CHAPTER 2G
FILE SC2GD1

TEST NUMBER	1	2	3
TEST DATE	1/30/91	1/31/91	2/5/91
SPOUTED BED, ACFM	7	5	7
SPOUTED BED RISER, FPM	252	180	252
SPOUTED BED ELUTRIATION, FPM	28	20	28
FLUIDIZED BED, ACFM	5	4	5
FLUIDIZED BED, FPM	20	16	20
SPOUTED BED PRESSURE DROP, IWG	1.7	2	2.2
FLUIDIZED BED PRESSURE DROP, IWG	3.8	3.5	2.8
YIELD FINISHED PRODUCT, %	93.7	88.4	99.8
YIELD SPOUTED BED "FINES", %	3.1	6.4	.1
YIELD FLUIDIZED BED "FINES", %	3.2	5.2	.1
FINISHED PRODUCT MMD, MICRONS	49	47	-
SPOUTED BED "FINES" MMD, MICRONS	10	10	-
FLUIDIZED BED "FINES" MMD, MICRONS	12	12	-
TEST FEED MMD, MICRONS	48	42	-
FEED SOURCE:	ALUMINA:SILICA	ALUMINA:SILICA	ALUMINA:COAL FLY ASH
	5:0.2	5:0.2	92:8
	(96.15:3.85)	(96.15:3.85)	
RECONSTRUCTED FEED:			
% > FEED MMD	49.3	57.5	-
COMPARISON TO FEED MMD	=50%	>50%	-

* TABLE 2G-1 *

FIGURE 2G-1 *

REPORT ON THE SEPARATION OF POWDERS IN A FLUIDIZED BED

by

Gabriel Tardos

Department of Chemical Engineering

The City College of New York

New York, NY 10032

1) Introduction

The goal of this research was to separate a mixture of coarse alumina (30-100 μ m) and fine silica (0.5-20 μ m) into two fractions using a fluidized bed at 400°C. The objectives were summarized in the research proposal submitted to GE on May 8, 1990:

- a) investigate the feasibility of separation of coarse and fine powders from a mixture using a batch fluidized bed,
- b) determine the range of operating conditions under which efficient separation is possible in a lab scale fluidized bed at temperatures up to 700°F.

The principle of operation and the details of the fluidized bed apparatus were described in the research proposal and will be only

briefly reviewed here. In order to perform separation and elutriation of two dissimilar powders, the fluidized bed has to be operated at a gas velocity, U_0 , higher than the minimum fluidization but lower than the elutriation velocity of the coarser and heavier powder (please see Figure 1 in the research proposal). The first set of experiments was therefore performed to measure these characteristics and the results are given in the next section. Actual separation experiments using a 90%/10% coarse/fine mixture was performed subsequently in order to demonstrate the feasibility of the process and these results are reported in Section 3. Conclusions and proposed future work are given in the last section.

2) Measurement of Fluidization Characteristics

In order to measure these characteristics, the coarse alumina powder was divided by sieving into three fractions with maximum diameters of $44\mu\text{m}$, $116\mu\text{m}$ and $180\mu\text{m}$, respectively. A size distribution of the same powder is given in Figure 1 as obtained from a Malvern Particle Size Analyzer; this distribution does not agree with either the sieve analysis or the distribution curve provided by GE and obtained by a sedimentation method. One has to note here however that the first two distributions (Malvern and sieve) are somewhat closer than the other two (sieve and Sedigraph).

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Pressure drop versus superficial gas velocity curves were generated for all three cuts of the powder at room temperature and at 400°C and these are reproduced in Figures 2 and 3 as a function of particle size. The minimum fluidization velocities at both temperatures are reproduced in Figure 4. The elutriation velocity was also determined at both temperatures but only for the smallest cut (particle size smaller than 44 μ m) and the results are reproduced in Figures 5a and 5b. Elutriation takes place over a large velocity range due to clustering and the existence of some fines; as seen, elutriation starts at room temperature at about $U_0 = 30$ cm/sec while the whole bed becomes elutriated when the velocity reaches about 55 cm/sec. At 400°C however, elutriation starts at about 8 cm/sec - all these results were obtained in a bed of 3 inches in diameter and a free board of about two feet (60cm). From Figures 4 and 5 it is evident that the bed at room temperature can be operated between about $U_{mf} = 1$ cm/sec to $U_f = 30$ cm/sec while the bed at 400°C between $U_{mf} = 0.4$ cm/sec and $U_f = 8$ cm/sec. In subsequent experimentation an average gas velocity of $U_0 = 4$ cm/sec at 400°C was used which is about $10U_{mf}$ at this temperature.

For the sake of completeness, Figure 6 shows the size distribution of the fine silica powder as obtained from the Malvern Analyzer; this distribution does not agree with the one provided to us by GE and obtained from a sedigraph. The important conclusion from Figures 1 and 6 is that only 0.8% of the alumina is finer than about 30 μ m while 99.9% of the silica is smaller than this limit.

Even if the Malvern measurement is somewhat in error, this is of great significance when mixing and separation of these powders is attempted since the "tail" of the distribution toward fines below $30\mu\text{m}$ will signal the existence of the silica powder in the mixture.

3) Separation of Powders in the Fluid Bed

Three actual final runs were performed (in addition to about 10 preliminary runs) two of which, denoted #18 and #19, were carried out with mixtures while #17 was performed with the coarse powder alone. During a typical experiment, the bed was loaded with a mixture of 90% alumina and 10% silica (or only alumina in the case of experiment #17) and the bed was then fluidized at a gas velocity of $U_0 = 4 \text{ cm/sec}$ at 410°C for about two hours. The temperature in the bed and the pressure drop through the bed were continuously monitored; a pressure drop versus time curve is reproduced in Figure 7 (the two curves were obtained by using a U tube and a pressure transducer connected to a data acquisition system). As can easily be seen, most of the elutriation takes place in the first 45-55 minutes, after which no significant elutriation can be detected.

In addition to the above measurements, the mixture is weighed before and after fluidization while the elutriate is sampled in a high efficiency cyclone; the measurements are reproduced in Table 1. From a total of about 490 g, an average of 456 g are retained

in the bed after about two hours of fluidization. From the difference, about 26 g are separated in the cyclone while the remainder is collected in a high efficiency filter mounted downstream. Assuming that the mixture indeed contains 10% fines, the total separation efficiency is between 63-72% as seen in Table 1. The corrected efficiency (line 6) was obtained by subtracting the elutriation of pure alumina (experiment #17, column 3) from the total elutriate of runs #18 in #19 thus obtaining efficiencies of 46-55%. Clearly none of these numbers are rigorously correct since some alumina particles will always break during fluidization whether the fines are present or not but the effect will be less pronounced when fines are present and thus real efficiencies will be somewhere between the two sets of values reported. Table 1 also contains some data about the efficiency of the cyclone used.

During the experiments, powder samples were taken and size analysis was performed for the mixture and for the fluidized powder after two hours of continuous fluidization; these results are reproduced in Figures 8a and 8b for run #18 and 9a and 9b for run #19. Some relevant data from these Figures is also given in Table 2; as seen, the presence of fines in the mixture (less than $31\mu\text{m}$ in diameter) is close to the nominal value of 10% at which the powders were originally mixed. The final content of fines varies from 3.9 to 5.3% and separation efficiencies calculated on this basis are of the order of magnitude of the corrected efficiencies in Table 1. Clearly none of the procedures to calculate these efficiencies

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(from a mass balance in Table 1 or from a size distribution in Table 2) are rigorously correct; in both cases assumptions had to be made and hence errors are generated, but over all it is quite remarkable how close these results are despite the nonideal conditions encountered during the experiments. Much more precise results could be obtained with a nondegrading alumina powder.

Figures 10a and 10b contain the size analysis of the elutriate captured in the cyclone during run #18 and #19, respectively. As seen, there are only about 10-12% of particles in the elutriate which are larger than about $31\mu\text{m}$ (and hence would represent alumina powder) of the total weight lost from the bed of 31-35 g (see Table 1). This represents on the average a total loss of about 0.74% from the mixture and 0.8% of the original alumina powder; this would therefore be the amount of large particles to be made up after a two hour fluidization run.

4) Conclusions

Fluidization characteristics were determined and separation of a mixture of coarse and fine particles was tested to demonstrate the feasibility of the process. From both mass balance and particle size distribution calculations, it was shown that the separation efficiencies of the order of 50-70% can be achieved at around 400°C over approximately 50 minutes of fluidization. It was also shown that only about 0.8% of the coarse material is elutriated.

The obtained results are somewhat preliminary in nature due to the fact that after mixing, the powders could not be identified and hence any breakdown of the larger particles and/or agglomeration of the fines could, in principle, introduce errors into the results. It is therefore proposed that similar experiments be carried out using powders which can be chemically identified once they are mixed. Using such powders, an optimization of the process would be possible as opposed to the present procedure where, due to the scatter of data and the inherent assumptions, any trend would be masked.

TABLE 1: Fluidization Experiments - Separation Results

	<u>Mixture</u> <u>#19</u>	<u>Mixture</u> <u>#18</u>	<u>Alumina</u> <u>Only</u> <u>#17</u>
Initial Weight	490.00	490.00	450.00
Final Weight	458.90	454.64	441.81
Total Weight Lost	31.10	35.36	8.19
Total Initial Weight of Silica	49.00	49.00	none
Efficiency [%]	63.47	72.16	----
Corrected Efficiency [%]	46.75	55.44	----
Fines Collected in Cyclone	26.64	25.96	5.30
Cyclone Efficiency [%]	85.53	73.41	64.71

TABLE 2: Separation Efficiency Based on Size Distribution**Percent less than 31 μ m Efficiency, %**

A) Silica Powder	99.9	----
B) Alumina Powder	0.8	----
Original Mixture		
#18*	10.5	----
#19*	9.4	----
Final Mixture (after fluidization)		
#18	3.9	62.85
#19	5.3	43.61

* Nominal value obtained from mechanical mixing of powders A and B at 10% and 90% respectively.

Experiment-No. 17 Sample size
Analyzed in Water
300 ea Lens

Figure 1: Alumina powder size analysis.

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High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	Span 0.86
24.4	100	24.4	99.9	114	68.8	51.3	5.7	23.1	0.7	D(4, 3)
24.4	99.9	24.4	99.8	114	68.8	47.7	4.6	21.4	0.5	102.39µm
24.4	99.8	24.4	99.7	114	68.8	44.4	3.7	19.9	0.3	
24.4	99.7	24.4	99.6	114	68.8	41.2	2.8	18.1	0.2	D(3, 2)
24.4	99.6	24.4	99.5	114	68.8	38.0	2.0	17.2	0.1	80.15µm
24.4	99.5	24.4	99.4	114	68.8	34.7	1.5	16.0	0.0	
24.4	99.4	24.4	99.3	114	68.8	31.5	1.1	14.9	0.0	D(2, 0.91)
24.4	99.3	24.4	99.2	114	68.8	28.3	0.8	13.9	0.0	145.83µm
24.4	99.2	24.4	99.1	114	68.8	25.1	0.7	12.9	0.0	
24.4	99.1	24.4	99.0	114	68.8	22.0	0.7	12.0	0.0	D(1, 0.11)
24.4	99.0	24.4	98.9	114	68.8	18.8	0.7	11.2	0.5	61.59µm
24.4	98.9	24.4	98.8	114	68.8	15.7	0.7			
24.4	98.8	24.4	98.7	114	68.8	12.6	0.7			
24.4	98.7	24.4	98.6	114	68.8	9.5	0.7			
24.4	98.6	24.4	98.5	114	68.8	6.4	0.7			
24.4	98.5	24.4	98.4	114	68.8	3.3	0.7			
24.4	98.4	24.4	98.3	114	68.8	0.2	0.7			
24.4	98.3	24.4	98.2	114	68.8		0.7			
24.4	98.2	24.4	98.1	114	68.8		0.7			
24.4	98.1	24.4	98.0	114	68.8		0.7			
24.4	98.0	24.4	97.9	114	68.8		0.7			
24.4	97.9	24.4	97.8	114	68.8		0.7			
24.4	97.8	24.4	97.7	114	68.8		0.7			
24.4	97.7	24.4	97.6	114	68.8		0.7			
24.4	97.6	24.4	97.5	114	68.8		0.7			
24.4	97.5	24.4	97.4	114	68.8		0.7			
24.4	97.4	24.4	97.3	114	68.8		0.7			
24.4	97.3	24.4	97.2	114	68.8		0.7			
24.4	97.2	24.4	97.1	114	68.8		0.7			
24.4	97.1	24.4	97.0	114	68.8		0.7			
24.4	97.0	24.4	96.9	114	68.8		0.7			
24.4	96.9	24.4	96.8	114	68.8		0.7			
24.4	96.8	24.4	96.7	114	68.8		0.7			
24.4	96.7	24.4	96.6	114	68.8		0.7			
24.4	96.6	24.4	96.5	114	68.8		0.7			
24.4	96.5	24.4	96.4	114	68.8		0.7			
24.4	96.4	24.4	96.3	114	68.8		0.7			
24.4	96.3	24.4	96.2	114	68.8		0.7			
24.4	96.2	24.4	96.1	114	68.8		0.7			
24.4	96.1	24.4	96.0	114	68.8		0.7			
24.4	96.0	24.4	95.9	114	68.8		0.7			
24.4	95.9	24.4	95.8	114	68.8		0.7			
24.4	95.8	24.4	95.7	114	68.8		0.7			
24.4	95.7	24.4	95.6	114	68.8		0.7			
24.4	95.6	24.4	95.5	114	68.8		0.7			
24.4	95.5	24.4	95.4	114	68.8		0.7			
24.4	95.4	24.4	95.3	114	68.8		0.7			
24.4	95.3	24.4	95.2	114	68.8		0.7			
24.4	95.2	24.4	95.1	114	68.8		0.7			
24.4	95.1	24.4	95.0	114	68.8		0.7			
24.4	95.0	24.4	94.9	114	68.8		0.7			
24.4	94.9	24.4	94.8	114	68.8		0.7			
24.4	94.8	24.4	94.7	114	68.8		0.7			
24.4	94.7	24.4	94.6	114	68.8		0.7			
24.4	94.6	24.4	94.5	114	68.8		0.7			
24.4	94.5	24.4	94.4	114	68.8		0.7			
24.4	94.4	24.4	94.3	114	68.8		0.7			
24.4	94.3	24.4	94.2	114	68.8		0.7			
24.4	94.2	24.4	94.1	114	68.8		0.7			
24.4	94.1	24.4	94.0	114	68.8		0.7			
24.4	94.0	24.4	93.9	114	68.8		0.7			
24.4	93.9	24.4	93.8	114	68.8		0.7			
24.4	93.8	24.4	93.7	114	68.8		0.7			
24.4	93.7	24.4	93.6	114	68.8		0.7			
24.4	93.6	24.4	93.5	114	68.8		0.7			
24.4	93.5	24.4	93.4	114	68.8		0.7			
24.4	93.4	24.4	93.3	114	68.8		0.7			
24.4	93.3	24.4	93.2	114	68.8		0.7			
24.4	93.2	24.4	93.1	114	68.8		0.7			
24.4	93.1	24.4	93.0	114	68.8		0.7			
24.4	93.0	24.4	92.9	114	68.8		0.7			
24.4	92.9	24.4	92.8	114	68.8		0.7			
24.4	92.8	24.4	92.7	114	68.8		0.7			
24.4	92.7	24.4	92.6	114	68.8		0.7			
24.4	92.6	24.4	92.5	114	68.8		0.7			
24.4	92.5	24.4	92.4	114	68.8		0.7			
24.4	92.4	24.4	92.3	114	68.8		0.7			
24.4	92.3	24.4	92.2	114	68.8		0.7			
24.4	92.2	24.4	92.1	114	68.8		0.7			
24.4	92.1	24.4	92.0	114	68.8		0.7			
24.4	92.0	24.4	91.9	114	68.8		0.7			
24.4	91.9	24.4	91.8	114	68.8		0.7			
24.4	91.8	24.4	91.7	114	68.8		0.7			
24.4	91.7	24.4	91.6	114	68.8		0.7			
24.4	91.6	24.4	91.5	114	68.8		0.7			
24.4	91.5	24.4	91.4	114	68.8		0.7			
24.4	91.4	24.4	91.3	114	68.8		0.7			
24.4	91.3	24.4	91.2	114	68.8		0.7			
24.4	91.2	24.4	91.1	114	68.8		0.7			
24.4	91.1	24.4	91.0	114	68.8		0.7			
24.4	91.0	24.4	90.9	114	68.8		0.7			
24.4	90.9	24.4	90.8	114	68.8		0.7			
24.4	90.8	24.4	90.7	114	68.8		0.7			
24.4	90.7	24.4	90.6	114	68.8		0.7			
24.4	90.6	24.4	90.5	114	68.8		0.7			
24.4	90.5	24.4	90.4	114	68.8		0.7			
24.4	90.4	24.4	90.3	114	68.8		0.7			
24.4	90.3	24.4	90.2	114	68.8		0.7			
24.4	90.2	24.4	90.1	114	68.8		0.7			
24.4	90.1	24.4	90.0	114	68.8		0.7			
24.4	90.0	24.4	89.9	114	68.8		0.7			
24.4	89.9	24.4	89.8	114	68.8		0.7			
24.4	89.8	24.4	89.7	114	68.8		0.7			
24.4	89.7	24.4	89.6	114	68.8		0.7			
24.4	89.6	24.4	89.5	114	68.8		0.7			
24.4	89.5	24.4	89.4	114	68.8		0.7			
24.4	89.4	24.4	89.3	114	68.8		0.7			
24.4	89.3	24.4	89.2	114	68.8		0.7			
24.4	89.2	24.4	89.1	114	68.8		0.7			
24.4	89.1	24.4	89.0	114	68.8		0.7			
24.4	89.0	24.4	88.9	114	68.8		0.7			
24.4	88.9	24.4	88.8	114	68.8		0.7			
24.4	88.8	24.4	88.7	114	68.8		0.7			
24.4	88.7	24.4	88.6	114	68.8		0.7			
24.4	88.6	24.4	88.5	114	68.8		0.7			
24.4	88.5	24.4	88.4	114	68.8		0.7			
24.4	88.4	24.4	88.3	114	68.8		0.7			
24.4	88.3	24.4	88.2	114	68.8		0.7			
24.4	88.2	24.4	88.1	114	68.8		0.7			
24.4	88.1	24.4	88.0	114	68.8		0.7			
24.4	88.0	24.4	87.9	114	68.8		0.7			
24.4	87.9	24.4	87.8	114	68.8		0.7			
24.4	87.8	24.4	87.7	114	68.8		0.7			
24.4	87.7	24.4	87.6	114	68.8		0.7			
24.4	87.6	24.4	87.5	114	68.8		0.7			
24.4	87.5	24.4	87.4	114	68.8		0.7			
24.4	87.4	24.4	87.3	114	68.8		0.7			
24.4	87.3	24.4	87.2	114	68.8		0.7			
24.4	87.2	24.4	87.1	114	68.8		0.7			
24.4	87.1	24.4	87.0	114	68.8		0.7			
24.4	87.0	24.4	86.9	114	68.8		0.7			
24.4	86.9	24.4	86.8	114	68.8		0.7			
24.4	86.8	24.4	86.7	114	68.8		0.7			
24.4	86.7	24.4	86.6	114	68.8		0.7			
24.4	86.6	24.4	86.5	114	68.8		0.7			
24.4	86.5	24.4	86.4	114	68.8		0.7			
24.4	86.4	24.4	86.3	114	68.8		0.7			
24.4	86.3	24.4	86.2	114	68.8		0.7			
24.4	86.2	24.4	86.1	114	68.8		0.7			
24.4	86.1	24.4	86.0	114	68.8		0.7			
24.4	86.0	24.4	85.9	114	68.8		0.7			
24.4	85.9	24.4	85.8	114	68.8		0.7			
24.4	85.8	24.4	85.7	114	68.8		0.7			
24.4	85.7	24.4	85.6	114	68.8		0.7			
24.4	85.6	24.4	85.5	114	68.8		0.7			
24.4	85.5	24.4	85.4	114	68.8		0.7			
24.4	85.4	24.4	85.3	114	68.8		0.7			
24.4	85.3	24.4	85.2	114	68.8		0.7			
24.4	85.2	24.4	85.1	114	68.8		0.7

Figure 2: Pressure Drop vs. Superficial Velocity

No. 1&2&3, L=4 inches, Alumina dust, $T=20^{\circ}\text{C}$

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Figure 3; Pressure Drop vs. Superficial Velocity

No. 40-50-6, T=400 degrees, L=4 inches

Figure 4 : U_{mf} vs. Particle Diameter

No. 7 & 8

Figure 5a: U_{mf} and U_{elu} vs. Particle Diameter

No. 1422347, L=4 inches, T=22 C

Figure 5b: U_{mf} and U_{elu} vs. Particle Diameter

No. 40-50 Mesh, L=4 inches, T=600 C

MALVERN

Instruments SB.04 Fri 26 Oct 1990 Time 1:57 pm

Experiments Raw Silica Power
Analyzed in Water
63 ss lens

Figure 6: Silica powder size analysis

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High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	Span 2.44
11.8	100	24.0	99.7	10.8	63.4	4.84	38.9	2.18	14.2			D[4,3] 9.01 μ m
10.0	100	22.3	94.9	10.0	61.2	4.50	36.3	2.03	12.4			
8.0	100	19.3	90.7	8.0	56.6	3.9	33.3	1.88	10.9			D[3,2] 3.71 μ m
6.3	100	17.3	88.9	6.3	53.3	3.3	30.0	1.77	9.7			
5.0	100	15.5	84.4	5.0	49.7	2.9	27.8	1.63	8.8			D[x,0.9] 18.99 μ m
4.0	100	14.0	80.9	4.0	47.2	2.6	25.0	1.53	8.0			
3.2	100	12.5	76.4	3.2	45.0	2.3	22.7	1.41	7.3			D[y,0.1] 1.79 μ m
2.5	100	11.6	70.9	2.5	42.8	2.2	20.7	1.33	6.7			
2.0	100	10.8	64.0	2.0	40.6	2.34	18.4	1.22	4.9			D[y,0.5] 7.06 μ m
1.6	100	10.0	55.6	1.6	38.9	2.44	16.2					
Source = Sample Beam length = 2.2 mm Model indep												
Focal length = 63 mm Log. Diff. = 1.566												
Presentation = pil Obscuration = 0.2433 Volume Conc. = 0.0157%												
Volume distribution Sp. S.A 1.6157 m ² /cc.

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Centimeter

Inches

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6 of 7

Figure 7: Pressure drop vs time during a separation experiment

Experiment-No.18 Sample size
Analyzed in Water
300 μ m Lens

Figure 8a : Size distribution for mixture
Run # KP

2661 pil 1M00343

High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	Span
54	100	254	99.9	114	70.3	51.3	15.7	23.1	9.2	10.4	6.0	D[4.3]
524	99.9	236	99.8	106	62.7	47.7	14.6	21.4	9.1	9.64	6.0	92.55 μ m
488	99.9	219	99.8	98.6	54.8	44.4	13.7	19.9	9.0	8.97	6.0	
454	99.9	204	99.7	91.7	47.1	41.2	12.9	18.5	8.8	8.34	6.0	D[3.2]
422	99.9	190	99.4	85.3	40.0	38.4	12.2	17.2	8.3	7.76	5.9	33.42 μ m
392	99.9	176	98.3	79.3	33.9	35.7	11.6	16.0	8.2	7.21	5.7	
365	99.9	164	96.2	73.8	29.0	33.2	11.0	14.9	7.8	6.71	5.4	D[v, 0.9]
339	99.9	153	92.9	68.6	24.9	30.8	10.5	13.9	7.3	6.24	4.9	145.06 μ m
315	99.9	142	88.6	63.8	21.7	28.7	10.0	12.9	6.8	5.80	4.4	
293	99.9	132	83.3	59.3	19.2	26.7	9.7	12.0	6.4			D[v, 0.1]
273	99.9	123	77.2	55.2	17.2	24.8	9.4	11.2	6.1			28.52 μ m
Source = :Sample												D[v, 0.5]
Focal length = 300 μ m												94.32 μ m
Presentation = pil												
Beas length = 2.2 μ m												
Log. Diff. = 3.233												
Obscuration = 0.2388												
Volume distribution												
Model indep												
Volume Conc. = 0.1384%												
Sp.S.A 0.1795 μ^2 /cc.

Experiment-No. 18 Final Material in Bed
Analyzed in Water
300 μ m Lens

1

Figure 8b : Size distribution
for final bed material
Run #18

2661 pil 1M00343

High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	Span 0.98
564	100	254	99.9	114	71.5	51.3	10.6	23.1	3.9	10.4	2.6	D[4.3]
524	100	236	99.9	106	63.4	47.7	9.2	21.4	3.9	9.64	2.5	96.41μm
488	99.9	219	99.9	98.6	54.3	44.4	7.7	19.9	3.9	8.97	2.3	
454	99.9	204	99.7	91.7	45.7	41.2	6.2	18.5	3.9	8.34	2.3	D[3.2]
422	99.9	190	99.3	85.3	37.3	38.4	5.1	17.2	3.5	7.76	2.4	52.73μm
392	99.9	176	98.3	79.3	30.0	35.7	4.4	16.0	3.2	7.21	2.3	
363	99.9	164	96.3	73.8	24.0	33.2	4.1	14.9	2.9	6.71	2.2	D[y, 0.9]
339	99.9	153	93.3	68.6	19.2	30.8	3.9	13.9	2.7	6.24	2.0	143.30μm
313	99.9	142	89.4	63.8	15.8	28.7	3.9	12.9	2.6	5.80	1.8	
293	99.9	132	84.5	59.3	13.4	26.7	3.9	12.0	2.6			D[y, 0.1]
273	99.9	123	78.6	55.2	11.9	24.8	3.9	11.2	2.6			49.77μm
Source = :Sample												D[y, 0.5] 95.04μm
Focal length = 300 μm												
Presentation = pil												
Beam length = 2.2 μm Log. Diff. = 3.399 Obscuration = 0.2205 Volume distribution												
Model indep Volume Conc. = 0.1994% Sp.S.A 0.1138 μ²/cc.

Exp No 19 Sample size

Figure 9a : Size distribution for mixture
Run # 19

2661 pil 1M00343

High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	Span 1.26
54	100	244	97.0	114	63.3	51.3	12.3	23.1	8.2	10.4	5.9	D[4,3]
524	99.5	236	97.0	106	56.2	47.7	12.2	21.4	8.1	9.64	5.7	107.94 μ m
488	99.0	219	97.0	98.6	49.0	44.4	12.0	19.9	8.0	8.97	5.5	D[3,2]
454	98.6	204	96.8	91.7	41.9	41.2	11.7	18.5	7.9	8.34	5.2	39.19 μ m
422	98.1	190	96.0	85.3	35.1	38.4	11.2	17.2	7.8	7.76	5.0	
385	97.7	176	94.3	79.3	28.8	35.7	10.6	16.0	7.6	7.21	4.6	D[v,0.9]
363	97.4	164	91.8	73.8	23.3	33.2	10.0	14.9	7.3	6.71	4.1	159.35 μ m
339	97.2	153	87.5	68.6	18.8	30.8	9.4	13.9	7.1	6.24	3.5	
315	97.1	142	82.5	63.8	13.5	28.7	8.9	12.9	6.7	5.80	3.0	D[v,0.1]
293	97.1	132	76.7	58.3	13.6	26.7	8.5	12.0	6.4			33.32 μ m
273	97.0	123	70.3	55.2	12.7	24.8	8.3	11.2	6.1			
Source = :Sample Beam length = 2.2 mm Model indp Focal length = 300 mm Log. Diff. = 3.820 Presentation = pil Obscuration = 0.2487 Volume Conc. = 0.1701% Volume distribution Sp.S.A 0.1531 m ² /cc.												D[v,0.5]
												99.65 μ m

Experiment No. 19 Final Material in Bed
Analyzed in Water
300 μ m Lens

1

Figure 9b : Size distribution for
final bed material
Run #19

2661 pil 1M00343

High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	Span
												0.98
564	100	254	99.9	114	69.1	51.3	11.0	23.1	4.9	10.4	3.4	D[4,3]
524	100	236	99.9	106	60.1	47.7	9.5	21.4	4.8	9.64	3.3	97.89 μ m
488	99.9	219	99.9	98.6	50.4	44.4	8.2	19.9	4.7	8.97	3.3	
454	99.9	204	99.7	91.7	41.1	41.2	7.0	18.3	4.6	8.34	3.2	D[3,2]
422	99.9	190	99.3	85.3	33.0	38.4	6.1	17.2	4.5	7.76	3.1	47.97 μ m
392	99.9	176	98.2	79.3	26.6	35.7	5.6	16.0	4.4	7.21	3.0	
365	99.9	164	96.1	73.8	22.1	33.2	5.4	14.9	4.2	6.71	2.8	D[v,0.9]
339	99.9	153	92.9	68.6	18.8	30.8	5.3	13.9	4.1	6.24	2.5	144.82 μ m
315	99.9	142	88.7	63.8	16.3	28.7	5.2	12.9	3.8	5.80	2.3	
293	99.9	132	83.4	59.3	14.4	26.7	5.1	12.0	3.6			D[v,0.1]
273	99.9	123	76.9	55.2	12.6	24.8	5.0	11.2	3.5			48.80 μ m
Source = :Sample												D[v,0.5] 98.30 μ m
Beam length = 2.2 mm												
Log. Diff. = 3.389												
Model indep												
Focal length = 300 mm												
Obscuration = 0.2147												
Volume Conc. = 0.1761%												
Presentation = pil												
Volume distribution												
Sp.S.A 0.1251 m ² /cc.

MALVERN

Instruments SB.8A Fri 26 Oct 1990 Time 1:17 pm

Experiment 18. Powder in cyclone
Analyzed in Water
63 mm lens

Figure 10a : Size analysis of the
cyclone catch
Run # 18

2661 pil 1M00343

High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	Span
												1.73
118	100	53.3	99.4	24.0	72.9	10.8	26.2	4.84	5.3	2.18	0.4	D[4,3]
110	100	49.5	98.8	22.3	68.8	10.0	22.7	4.50	4.4	2.03	0.3	18.39 μ m
102	100	46.1	97.9	20.7	64.8	9.31	20.0	4.19	3.6	1.88	0.2	
93.2	100	42.8	96.8	19.3	60.8	8.66	17.9	3.89	3.1	1.75	0.2	D[3,2]
84.6	100	39.8	95.3	17.9	56.8	8.05	16.1	3.62	2.6	1.63	0.1	11.97 μ m
82.4	100	37.0	93.4	16.7	52.9	7.49	14.5	3.37	2.1	1.51	0.1	
76.6	100	34.4	91.1	15.5	48.9	6.97	12.9	3.13	1.7	1.41	0.1	D[v,0.9]
71.2	100	32.0	88.1	14.4	44.7	6.48	11.3	2.91	1.4	1.31	0.1	33.50 μ m
66.2	100	29.8	84.8	13.4	40.1	6.02	9.7	2.71	1.1	1.22	0.1	
61.6	99.9	27.7	81.0	12.5	35.3	5.60	8.1	2.52	0.8			D[v,0.1]
57.3	99.8	25.8	77.0	11.6	30.5	5.21	6.6	2.34	0.6			6.10 μ m
Source = :Sample												D[v,0.5]
Beam length = 2.2 mm												
Log. Diff. = 4.225												
Focal length = 63 mm												15.79 μ m
Obscuration = 0.2037												
Presentation = pil												
Volume distribution												
Model indp												Sp.S.A 0.5013 m ² /cc.
Volume Conc. = 0.0414%

CCNY CHEMICAL ENGINEERING

Experiment 19. Powder in cyclone
Analyzed in Water
63 mm lens

Figure 106: Size analysis of the
cyclone catch
Run #19

2661 pil 1M00343

High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	High Size	Under %	Span 1.69
118	100	53.3	99.5	24.0	77.3	10.8	27.4	4.84	4.8	2.18	0.4	DF[4,31]
110	100	49.5	99.0	22.3	73.4	10.0	23.9	4.50	3.9	2.03	0.3	17.49µm
102	100	46.1	98.3	20.7	69.4	9.31	21.0	4.19	3.3	1.88	0.2	DF[3,21]
93.2	100	42.8	97.4	19.3	65.2	8.66	18.8	3.89	2.4	1.73	0.2	11.73µm
84.6	100	39.8	96.2	17.9	60.9	8.05	16.8	3.62	2.0	1.63	0.1	
82.4	100	37.0	94.7	16.7	56.4	7.49	14.8	3.37	2.0	1.51	0.1	DF[v,0.9]
76.6	100	34.4	92.7	15.5	51.7	6.97	12.9	3.13	1.7	1.41	0.1	31.70µm
71.2	100	32.0	90.4	14.4	46.9	6.48	11.0	2.91	1.3	1.31	0.1	DF[v,0.1]
66.2	100	29.8	87.6	13.4	41.4	6.02	9.2	2.71	1.1	1.22	0.1	6.23µm
61.6	99.9	27.7	84.4	12.5	36.7	5.60	7.4	2.52	0.8			
57.3	99.8	25.8	80.9	11.6	31.8	5.21	5.9	2.34	0.6			
Source = :Sample Beam length = 2.2 mm Model indp												DF[v,0.5]
Focal length = 63 mm Log. Diff. = 4.290												15.08µm
Presentation = pil Obscuration = 0.1892 Volume Conc. = 0.0373%												
Volume distribution Sp.S.A 0.5115 m ² /cc.

TAB 9

4/10/17

DOE/GETS TOPICAL REPORT
CHAPTER 3

CHAPTER 3

Commensurate with Task 3, Component Development.

Task 3.2 & 3.3

Laboratory test facility, Cold flow test, Full size Envelope Filter Casing,
Full size Envelope Filter Elements

Introduction

The purpose of this program task was to perform the necessary laboratory testing to project previously smaller-than-full size concepts to full size component design. The intention was to perform these studies as laboratory cold flow procedures.

Two Component Development tasks were envisioned during early program planning.

Full Size Envelope Filter Casing:

The intention of this task was to investigate gas flow and particulate distribution characteristics which resulted from the space and size constraints imposed upon the design of the Envelope Filter casing, filter inlet plenum with integral sorbent storage bin, and filter approach ductwork. This task was intended to include some representation of filter envelope geometry, but not to include the complexity of replica representation of the filter envelope filter media. However, execution of this program task was rejected because of insufficient time and inadequate facilities relative to the program benefits that would be realized. Although some consideration was also given to performing a reduced geometric scale version of the complete Envelope Filter System, this too was rejected for execution.

Modular representation of full size filter envelope elements:

The intent of this planned task was to create a test facility of full size replica design filter envelopes. A test facility for this task purpose was planned to contain a minimum number of filter elements which would represent inter-envelope particulate dynamics characteristics. Of particular concern was the design of filter envelope filter media support and attachment to the envelope frames, as well as the design of the pulse air delivery manifold. Also intended for investigation was the interaction between adjacent envelopes during cleaning, both with and without the use of internal baffles located between adjacent envelopes.

DOE/GETS TOPICAL REPORT CHAPTER 3

A design for the modular test facility was completed and is described by GEESI drawings S9513/FA-890 through S9513/FA-899 enclosed in Appendix 3. This facility illustrates a non-replica design of filter inlet ductwork which includes consideration for creating uniform gas flow and test particulate to four full size replica design filter envelopes. Test facility filter outlet ductwork was also a non-replica representation of a full size system, but was as required for laboratory installation and operation. The configuration of the pulse air delivery manifold was a replication of a planned full size Envelope Filter design.

The design of the filter media envelope frames was a collaboration by GEESI and Memtec America Corp./Fluid Dynamics, the vendor selected for supply of the filter media. The use of the vendor for this effort was a procedure planned to utilize the vendor's experience for design of the filter media support and for attachment of the filter media to the envelope frames.

The development of an envelope frame design devoted much attention to the weight of the frame, since the composite of all the frames installed in the filter casing represented a significant amount of the composite filter system weight. Four variations were designed and fabricated by the vendor. It was an intention of the program to install each of the four envelopes in the modular cold flow test facility for evaluation. However, insufficient program schedule time did not permit use of the test facility for selection of the full size system design. A design was selected by inspection of the four examples on the basis of a best compromise between weight and rigidity. This design is illustrated by Memtec Drawing 021342 which is enclosed in Appendix 3.

Although the modular cold flow test facility was not constructed and tested, the design effort was valuable experience for the later design of the full size Envelope Filter system.

Task 3.2 & 3.3

Development of Sorbent/Precoat vendor sources

Although not previously included as a Component Development task, there did exist a program need for the development of sources of particulate material to serve the dual purpose of precoat particulate to enhance barrier filter media cleaning and to provide sorbent properties for SO₂ and NO_x reduction. Previous discussion of test results for the single cylinder CWS^x fuel engine Envelope Filter explained that copper oxide coated alumina precoat/sorbent was produced in limited quantities by batch laboratory procedures. Consideration of the quantities of this precoat/sorbent which would be required for operation of the full gas flow Envelope Filter made it imperative to develop a commercial vendor source for an adequate supply of precoat/sorbent material.

DOE/GETS TOPICAL REPORT CHAPTER 3

Previous consideration of sorbent regeneration showed that an MMD of approximately 50 microns was appropriate, and such alumina was used for earlier cold flow Envelope Filter testing as well as for later hot gas Envelope Filter testing. Specification of the alumina substrate for vendor produced copper oxide coated alumina gave serious consideration to the specific surface of the alumina powder in addition to a specification of particle size distribution. This characteristic had not been considered in the selection of alumina used for previous test purposes.

A commercial product alumina powder produced for catalyst use was selected as a basis for the specification of the precoat/sorbent alumina substrate. Vendors were developed to produce a 10,000 LB quantity of precoat/sorbent needed for full size Envelope Filter testing in accordance with GEESI specification. Samples were produced and submitted to GEESI for evaluation. Table 3-1 enclosed in Appendix 3 summarizes the GEESI specification and the analyses of vendor produced precoat/sorbent samples. It was concluded that each of the vendor sources satisfied the GEESI specification requirements, and GEESI purchased half of the anticipated full gas flow Envelope Filter test need from each vendor.

Consideration was also given to the use of a non-regenerative, or "throwaway" precoat/sorbent material. Sodium bicarbonate mineral Nahcolite is a common sorbent material used for dry in-duct injection SO_2 reduction of coal fuel flue gas. However, it was learned that commercially available Nahcolite for this purpose is too coarse for direct injection without inprocess pulverization. It was also learned that because of difficulty handling Nahcolite in a finely pulverized form, pulverization and storage of Nahcolite is not a satisfactory option.

However, there are sources available for commercially produced sodium bicarbonate products with varied particle size characteristics which are reported to be less subject to storage and handling problems than Nahcolite. Table 3-2, enclosed in Appendix 3, summarizes the particle size characteristics of various sodium bicarbonate products.

Use of a throwaway sorbent like sodium bicarbonate did not impose any particle size requirements, such as required for the copper oxide/alumina for regeneration purpose. In theory, sodium bicarbonate sorbent progresses to a finer and more porous characteristic when exposed to elevated temperature as a result of the evolution of H_2O and CO_2 gases. However, there was a decision to procure a sodium bicarbonate product which was most similar to the particle size distribution of the planned copper oxide/alumina precoat/sorbent in an effort to maintain similar material handling characteristics for the equipment which would be required to handle both sorbent materials. USP Powder and Sorbent Grade Fine products best satisfied this objective. The sorbent product procured for program testing was USP Powder because of the availability of a more convenient shipping container. A quantity of 10,000 lbs of the selected sodium bicarbonate product was also procured for full size Envelope Filter testing.

A P P E N D I X 3

DRAWING LIST

(APPENDIX 3)

DRAWING NUMBER

DRAWING SUBJECT

S9513/FA890

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER ARRANGEMENT**

FA891

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER CASING DETAILS**

FA892

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER CASING DETAILS**

FA893

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER CASING DETAILS**

FA894

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER AIR PIPING ASSEMBLY**

FA895

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER AIR PIPING DETAILS**

FA896

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER TUBE SHEET**

FA897

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER INLET DUCT & (CASING) DIVIDE PLATE**

FA898

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER INLET DUCT**

FA899

**(FULL SIZE ENVELOPE) COLD FLOW ENVELOPE
FILTER OUTLET DUCT**

HEMTEC 021342

(FILTER) MEDIA AND FRAME ASSEMBLY

DETAIL

VIEW
BLOW PIPES NOT SHOWN

ELEVATION

CWD FILE NO: 513FA890				
DESIGN	DESCRIPTION	DESCRIPTION	DESCRIPTION	DATE
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
APPROVED FOR ENGINEERING				
APPROVAL DATE

DETAIL

SECTION

ELEVATION

CAD FILE NO. 513FAB91

REVISION	DESCRIPTION	DESCRIPTION	DATE
DESIGN BY			
CHECKED BY			
REVISED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

FOR GENERAL NOTES SEE DWG. E/FA-890.

NO.	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
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12							

GE Environmental Systems COLD FLOW ENVELOPE FILTER 1 CASING DETAILS			
DATE: 0-3/28/92 DESIGNED BY: [Signature] DRAWN BY: [Signature]		CHECKED BY: [Signature] APPROVED BY: [Signature]	
AUTHORIZATION NO. S9513	DRAWING NUMBER FA-891	REVISION 0	
SCALE: NONE		PLOT 1=12	

472

SECTION
2
TYP. N.S. & F.S.

SECTION
3
TYP. N.S. & F.S.

SECTION
1
TYP. N.S. & F.S.

DAO FILE NO. 513FAS92

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

A DETAIL
891 TYP. (4) CORNERS

B DETAIL
892 TYP. BOTH ENDS OF L TO CASING WALL

C DETAIL
891

D DETAIL
892 TYP. BOTH ENDS OF L TO CASING WALL

E SECTION
892

F SECTION
892 TYPICAL HOPPER CORNER

G DETAIL
891

H VIEW
891

I SECTION
892

J VIEW
892 TYPICAL BOTH ENDS OF L1 1/2 X 1 1/2 (6) PLACES

K SECTION
891

L DETAIL
892

FOR GENERAL NOTES SEE DWG. E/FA-890

GE Environmental Systems			
COLD FLOW ENVELOPE FILTER CASING DETAILS			
DATE	DESIGN FOR CONSTRUCTION	BY	
APPROVAL	DESIGNER	REVISION	
S9513	FA-892	0	
SCALE: NONE		PLOT 1-12	

NO.	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
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473

REVISION	DESCRIPTION	DATE
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2	CHECKED BY	
3	DESIGNED BY	
4	APPROVED FOR SECTION	
5	APPROVED FOR CONSTRUCTION	
6	APPROVED DATE	

END FILE NO. 513-AR93

ENDS

1/8"

SECTION 13
TYP. (4) PLACES

SE
TYP. 883

3/8" X 1" LG.
HEX HD BOLT
W/ HEX NUT

SECTION 12

SE
TYP. 883

1/8" X 1/2"

1/8"

 DETAIL

DETAIL

10 SECTION
893

SECTION

DETAIL

g
893

DETAIL

FOR GENERAL NOTES SEE DWG. E/FA-890

[illegible]

	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
							D-2/28/92 WESBACH PLATED LOP 643000	DRAIN

8

7

6

PLAN

ELEVATION

(COVER
PLATE
REMOVED)

3/8" - 16 UNC X 1 1/4" LG.
HEX HD. BOLT W/ HEX NUT.
FLATWASHER & LOCKWASHER
BURR THREADS AT END OF
BOLT AFTER ASSEMBLY

WELD PPE NIPPLE
IN WALL AFTER ALL
HOLES IN BLOW PIPE
HAVE BEEN ALIGNED
OVER CENTERLINE OF
OPENING IN TUBE
SHEET

CNO FILE NO. 513FAB894

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DESIGNED BY			
CHECKED BY			
APPROVED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE			

47.

45 BLOW PIPE

44 BLOW PIPE

A DETAIL

3 895

END FILE NO. 513FA555

REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION
DESIGNED BY					
CHECKED BY					
REVIEWED FOR DESIGN					
APPROVED FOR ENGINEERING					
APPROVAL DATE					

8 7 6

3/8" DIA
STUD 1

SECTION 2

REVISION					
REVISION	DATE	DESCRIPTION	REVISION	DATE	DESCRIPTION
DESIGNED BY					
CHECKED BY					
REVIEWED FOR DESIGN					
APPROVED FOR ENGINEERING					
APPROVED DATE

[illegible]

NOTES:

1. FOR GENERAL NOTES SEE DRAWING E/FA-890.

<h1 style="text-align: center;">GE Environmental Systems</h1>			
<h2 style="margin: 0;">COLD FLOW ENVELOPE FILTER</h2>			
<div style="display: flex; align-items: center; justify-content: center; gap: 10px;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center; margin: 0 auto;">3</div> <h2 style="margin: 0;">TUBE SHEET</h2> </div>			
NAME		ENTER FOR ORIGINATOR	
APPROVED BY		REVISION NUMBER	
DATE		O

CAD FILE NO: 5137AB98

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION
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REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

FOR GENERAL NOTES SEE DRAWING E/TA-890

DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION

CE Environmental Systems			
COLD FLOW ENVELOPE FILTER			
INLET DUCT			
DESIGN FOR CONSTRUCTION		DATE	
AUTHORIZATION NO.		DRAWING NUMBER	
S9513		FA-898	
SCALE - NONE		PLOT 1-8	
REVISED		REVISION	
0		0	

474

CAD FILE NO. 513FAS99

REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
APPROVED FOR ENGINEERING				
APPROVAL DATE

71.87
RETAINING
FRAME

74.75

1.00 X 16" GAGE
STRIP (TYP)
(MOUNTING FRAME)

2.25 X 16 GAGE
STRIP (TYP)
(MOUNTING FRAME)

1.00
SQUA
(TYP.)

18.00 (TYP)
RETAINING FRAME
(8 REQUIRED)

3.00
(MAX. CENTERLINE DISTANCE OF RIVETS)

72.75

REV	DESCRIPTION	BY	APP'D	DATE	<div><p>MEMTEC America Corporation Land, FL 32724-9990 USA</p></div>	<div><p>PROPRIETARY DESIGN FOR DISCLOSURE This reproduction is a proprietary design and/or contains confidential information of Rail Systems, Inc., and, therefore, is to be held in strict confidence by the recipient. (1) The information shall be used only for review and reference purposes. (2) The information shall not be used or assumed to be used for procurement but in any way be provided to third parties. (3) The information shall not be reproduced or copied in whole or in part and (4) The information shall not be disclosed or given in any form to any third party without express consent in writing signed by an authorized representative of Rail Systems, Inc. Possession of this reproduction does not in itself convey any right to make, manufacture, use, or sell the design or information or any part thereof.</p></div>	<div><p>SCALE 1:5</p></div>
~	RELEASED FOR PRODUCTION	WS	SES	2/24/92			
A	REVISED TO AS BUILT	BW	SES	10/07/92			
B	REF. RIVET SPACING, ADDED MEDIA DATA, ADDED TYPICAL SECTION & EYE BOLT.	BW	SES	11/23/92			
	REF. ECN 07795						

MEDIA AND FRAME ASSEMBLY LOCOMOTIVE EXHAUST																																											
<div><p>QUANTITIES (EXCEPT AS NOTED)</p><table><tr><td>FRAC-300</td><td>— A1/04</td></tr><tr><td>3 PLATE EXTERNAL</td><td>— 2,010</td></tr><tr><td>2 PLATE INTERNAL</td><td>— 2,006</td></tr><tr><td>ANCHORS</td><td>— 4,020</td></tr><tr><td>DRILLED HOLES</td><td>— 2,006 — 2,006</td></tr><tr><td>DRILLED HOLES</td><td>— 2,006 (U.S.)</td></tr><tr><td>STEEL EDGE</td><td>— 803 — 815</td></tr><tr><td>175 ALL FINISHED SURFACES</td><td></td></tr></table></div>		FRAC-300	— A1/04	3 PLATE EXTERNAL	— 2,010	2 PLATE INTERNAL	— 2,006	ANCHORS	— 4,020	DRILLED HOLES	— 2,006 — 2,006	DRILLED HOLES	— 2,006 (U.S.)	STEEL EDGE	— 803 — 815	175 ALL FINISHED SURFACES		<div><table><tr><td>DRAWN</td><td>WALT</td><td>DATE</td><td>2/24/92</td></tr><tr><td>CHECKED</td><td>DAVE</td><td>DATE</td><td></td></tr><tr><td>APPROVED</td><td>DATE</td><td></td><td></td></tr><tr><td>SCALE</td><td>1:5</td><td></td><td></td></tr></table></div>	DRAWN	WALT	DATE	2/24/92	CHECKED	DAVE	DATE		APPROVED	DATE			SCALE	1:5			<div><table><tr><td>USED ON</td><td>SO 163870</td></tr><tr><td>NEXT ASBY</td><td>121342-01</td></tr><tr><td>DRAWING NUMBER</td><td>021342</td></tr><tr><td>DATE</td><td>11/92</td></tr></table></div>	USED ON	SO 163870	NEXT ASBY	121342-01	DRAWING NUMBER	021342	DATE	11/92
FRAC-300	— A1/04																																										
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CHECKED	DAVE	DATE																																									
APPROVED	DATE																																										
SCALE	1:5																																										
USED ON	SO 163870																																										
NEXT ASBY	121342-01																																										
DRAWING NUMBER	021342																																										
DATE	11/92																																										

TABLE 3-1
 PROPERTIES OF COPPER OXIDE COATED ALUMINA PRECOAT/SORBENT
 FILE SC3D1

CHARACTERISTIC	GEESI SPECIFICATION	CONDEA PURALOX SCCA 5/90 ALUMINA	DISCOVERY ALUMINA VENDOR	UNITED CATALYST VENDOR
GEESI SPECIFICATION:				
PARTICLE SIZE/SEDIGRAPH:				
APPROXIMATE MMD, MICRONS	40	42	-	-
MAXIMUM % < 30 MICRONS	10	2	-	-
MINIMUM % < 100 MICRONS	95	98	-	-
SPECIFIC SURFACE, SQ M/GRAM	80 TO 100	80 TO 100	-	-
COPPER OXIDE COATING:				
% WEIGHT	7 TO 10	-	-	-
LABORATORY RESULTS:				
PARTICLE SIZE/MICROSCAN:				
MMD, MICRONS	-	32	34	36
% < 30 MICRONS	-	40	35	20
% < 100 MICRONS	-	99	100	100
SPECIFIC SURFACE, SQ M/GRAM	-	97.6	81	88.25
COPPER, % WEIGHT	-	-	6.56	7.28
PROJECTED TO,				
COPPER OXIDE, % WEIGHT	-	-	8.2	9.1

 * TABLE 3-1 *

TABLE 3-2
 PARTICLE SIZE DISTRIBUTION OF SODIUM BICARBONATE PRODUCTS
 FILE SC3D2

CHARACTERISTIC	ARM AND HAMMER/CHURCH USP POWDER	AND DWIGHT CO. SORBENT GRADE	SORBENT GRADE FINE	SORBENT GRADE EXTRA FINE
VENDOR SPECIFICATION:				
TYPICAL GRANULATION,				
CUMULATIVE % RETAINED:				
60 MESH	-	0 TO 8	-	-
100 MESH	TRACE	-	TRACE	-
200 MESH	30 TO 40	20 TO 100	35 TO 45	1 TO 2
325 MESH	70 TO 75	60 TO 100	70 TO 80	26
EXPRESSED RELATIVE TO				
GEESI SPECIFICATION:				
% < 30 MICRON	2	5	0	55
% > 100 MICRON	19	45	23	0
30 MICRONS < % < 100 MICRONS	79	40	77	45
MMD, MICRONS	60	90	65	27

 * TABLE 3-2 *

TAB 10

44-5

**DOE/GETS TOPICAL REPORT
CHAPTER 4**

CHAPTER 4

Commensurate with Task 4, Integrated System Design.

Task 4.1 & 4.2

Full Size Envelope Filter System Design

The design of the full size Emissions Control system is described by GEESI design drawings which are included in Appendix 4. These drawings are preceded by Table 4-1 which is a list of all enclosed drawings by Drawing Number and Subject.

The design of the Full Size Envelope Filter was an assumed success activity, in consideration of yet-to-be-completed testing tasks on the single cylinder CWS fuel research diesel engine pilot scale Envelope Filter. A key requirement of the full size design was that the Envelope Filter could satisfy the size and space requirements for installation on a locomotive. Exceptions to this objective were with regard to the filter inlet connecting ductwork and the filter hopper evacuation conveyor system which were designed in accordance with site requirements.

System components which are not described by GEESI design drawings are:

- Two way gas flow damper to permit gas flow to the Envelope Filter system, or bypass to the existing stack.
- Mass gas flow meter located in the filter inlet connecting duct. This meter failed during preliminary operation of the filter and could not be restored to operation. A substitute gas flow determination procedure consisted of measurement of a scope of filter inlet ductwork pressure drop which was calibrated from theoretical fluid flow calculations.
- A continuous reading immersion level probe was installed in the sorbent storage bin. A continuous indication of decreasing immersion level verified continuous injection of sorbent/precoat particulate into the filter inlet gas flow.
- A variable speed rotary feed valve was installed to meter the rate of sorbent/precoat particulate injection into the filter inlet gas flow.
- Electrical heat tracing was installed on the filter inlet ductwork, as well as the filter casing and hopper. This heat tracing was maintained in continuous operation to preheat the filter system components before gas flow was started through the filter system, as well as to minimize gas flow temperature loss through the filter system insulation when gas flow was in operation.

**DOE/SETS TOPICAL REPORT
CHAPTER 4**

- GEESI Drawing S9513/FA845 illustrates various instrumentation locations for thermocouples in the filter connecting ductwork and in the filter casing, static pressure, and static pressure drop measurements, gas composition measurements in the filter inlet and filter outlet ductwork, a spare test connection for the injection of Neutralite precoat particulate prior to the start of the test, a test connection for the injection of ammonia during the test run, filter outlet test port connection for isokinetic sampling of filter effluent particulate concentration, and other spare connections which were not used.
- Sorbent/Precoat particulate was loaded into the storage bin from sealed 55 gallon drums fitted with an adapter to connect to the inlet hopper of a mechanical conveyor which discharged into the top of the storage bin. Use of 55 gallon drums for shipment, storage, and unloading was a program requirement and permitted transfer of sorbent/precoat material during inclement outdoor weather, if necessary.
- The Envelope Filter hopper was evacuated by a screw conveyor which ran the length of the trough hopper. The conveyor discharged into a transfer screw conveyor which brought the particulate to an accessible location for discharge through an adapter into a sealed 55 gallon drum fitted with a filtered vent and a level indicator to indicate a filled drum. After completion of a test run, discharged particulate could consist of a mixture of various materials such as Neutralite precoat particulate, reacted sorbent/precoat particulate, unreacted sorbent/precoat particulate (if the test was performed using >100% of stoichiometric sorbent requirement), and CWS ash particulate.
- A high efficiency air dryer system was installed to provide an appropriate supply of compressed air needed for air pulse cleaning of the filter media. The source of the compressed air was from the plant compressed air service.
- Operation of the Envelope Filter system during testing was performed from a control console consisting of a PLC based control panel using a GE Series 9030 Programmable Logic Controller and a colored CRT Operator Interface Terminal. This system provided an indication of all sub-systems status, as well as provided execution for operation of sub-system equipment such as filter envelope pulse air cleaning, bypass damper operation, sorbent rotary feed valve, sorbent loading system, sorbent unloading system, and ammonia injection system. The control console also included a Chart Recorder Data Logger for recording all data measurements, as well as a facility for the recording and continuous indication of key operating data by a PC computer for subsequent conversion to spreadsheet format for use in the evaluation of the test results. No controls for the operation of the engine or recording of engine operating conditions were included in this Emissions Control console system.

A P P E N D I X 4

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DOE/GETS TOPICAL REPORT
 CHAPTER 4

TABLE 4-1

Full Gas Flow Envelope Filter
 GEESI Design Drawing List

<u>Drawing Number</u>	<u>Drawing Subject</u>
S9513/GA850	GA of system.
S9513/PI100	P&ID of system.
S9513/SD800	Filter inlet ductwork.
S9513/SS800	Filter support steel.
S9513/SS801	Filter support steel.
S9513/SS802	Filter support steel.
S9513/FA830	Filter casing, hopper, inlet plenum, sorbent storage bin, inlet connecting ductwork.
S9513/FA831	Filter support beams
S9513/FA832	Filter casing.
S9513/FA833	Filter casing, inlet plenum.
S9513/FA834	Filter casing, inlet plenum.
S9513/FA835	Filter casing access doors.
S9513/FA836	Filter hopper.
S9513/FA837	Filter envelope pulse air system.
S9513/FA838	Pulse air blow pipes, pulse air reservoir manifold.
S9513/FA939	Filter inlet plenum access panels, filter envelope divider baffles.
S9513/FA840	Sorbent storage bin, filter inlet ductwork.
S9513/FA841	Filter inlet ductwork.
S9513/FA842	Filter envelope tubesheet.
S9513/FA843	Filter envelope tubesheet.
S9513/FA844	Filter outlet rain cap.
S9513/FA845	Filter instrument connection locations.
S9513/FA846	Filter instrument connection details.

2 ELEVATION VIEW

3 ELEVATION VIEW

CHD FILE NO. 5130A850

REVISION	DESCRIPTION	DESCRIPTION	DATE
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
PROJECT ENGINEER APPROVAL			
PROJECT MANAGER APPROVAL			
APPROVAL DATE

LOADING DIAGRAM

[illegible]

LOAD SYMBOLS () HAVE SAME MEANING
AS DEFINED IN ANSI A58.1-1982 SECT. 2.2
ALL LOADS ARE IN KIPS

[illegible]

OCT 2 1955 MF 50

495

P&ID FILE NO. 51371100				
DESIGNED BY		DESCRIPTION		DESCRIPTION
CHECKED BY				
APPROVED FOR DESIGN				
APPROVED FOR CONSTRUCTION				
PROJECT MANAGER APPROVAL				
APPROVED DATE				

5

4

3

2

1

NOTES:

1. FOR INSTRUMENT SYMBOLS AND GENERAL NOTES SEE DRAWINGS P-22' & P-802.
2. TYPICAL FOR NV-112AA TWPJ NV-11200 (20 VALVES).
3. GAS PORT SAMPLING - YES TO EXISTING GAS ANALYZER TEST CON GAS CART. GAS SAMPLE LINE W/ 1/2" - HEAT TRACED (NOT SHOWN).
4. PARTICULATE #4-1.
5. THREE (3) POINT TEMPERATURE SENSORS THREE (3) TAPS OF INLET (3) THERMOCOUPLES THREE (3) THERMOCOUPLES REQUIRED. TWENTY-SEVEN (27) TOTAL POINTS OF MEASUREMENT EACH TO RECORDER. SEE DETAIL DRAWING 12-014. THERMOCOUPLES MUST BE INSTALLED PRIOR TO SETTING FILTER IN PLACE.
6. FOR COMPRESSED AIR SUPPLY PIPING USE CARBON STEEL SCH. 40 PIPE.
7. FOR AMMONIA SUPPLY PIPING USE CARBON STEEL SCH. 40 PIPE.
8. THREE (3) POINTS TEMPERATURE SENSORS ONE THERMOCOUPLE ASSEMBLY REQUIRED THREE (3) POINTS FIVE EACH THERMOCOUPLE ASSEMBLY TO RECORDER. SEE DETAIL DRAWING 12-014. THERMOCOUPLES MUST BE INSTALLED PRIOR TO SETTING FILTER IN PLACE.
9. THREE (3) POINTS TEMPERATURE SENSORS ONE THERMOCOUPLE ASSEMBLY REQUIRED THREE (3) POINTS TO RECORDER. SEE DETAIL DRAWING 12-014.
10. FILLING EQUIPMENT FOR REAGENT BLO ON NO. 1.

GE Environmental Systems DOE/GETS			
PIPING AND INSTRUMENT DIAGRAM DIESEL ENGINE APC SYSTEM			
DATE FOR SUBMITTAL		DATE	
APPROVED BY		DRAWN BY	
S9513		PI-100	
SCALE - NONE		REVISED	
0			

OCT 19 0 002 M7 (P)

494

03 1/8" X 1/8" X 1/8" ALUMINUM CLAD (BOTH SIDES) FIBERGLASS CLOTH GASKET (DRILLING TO MATCH FLANGE DETAIL "A")
(1) REQUIRED

DESIGNED BY	W/2000000	W/2000000	W/2000000	W/2000000
DESIGNED BY				
REVIEWED FOR DESIGN				
APPROVED FOR CONSTRUCTION				
APPROVAL DATE				

5

4

3

2

1

DETAIL
800

SEE NOTE

DETAIL
800

NOTE: ANGLE FLANGE FOR DETAIL "E" SHALL BE TACK WELDED INTO POSITION TO ALLOW FOR ADJUSTMENT ANGLE SHALL BE FIELD WELDED AFTER FINAL FIT-UP.

DETAIL
800

DETAIL
800

02 SPACER DUCT

(1) REQUIRED - ESTIMATED ENGINEERING WT. = 320/

NOTES:

1. ALL DUCT PLATE TO BE 10 GAUGE A-36 STEEL
2. FLANGE MATERIAL TO BE A-36
3. ALL JOINTS AND WELDING AS SHOWN IN DETAILS
4. NO PAINT REQUIRED.

DETAIL
800

SECTION
800

NOTE: FABRICATOR SHALL HAVE THE OPTION OF BENDING DUCT PLATE CORNERS WHERE POSSIBLE

DETAIL
800

DETAIL
800

FIELD NOTE: EXISTING FLANGE SHALL BE DRILLED TO MATCH EXPANSION JOINT DRILLING.

REFERENCE DRAWINGS:

- IX-002 SURFACE PREPARATION & COATING SPEC.
 FA-845 INSTRUMENT CONNECTION DETAILS
 KD-015 AMMONIA SPARGER ASSEMBLY

GE Environmental Systems

ENGINE TEST CELL #4
 CWS DIESEL ENGINE
 EMISSION CONTROL EQUIPMENT
 FULL FLOW ENVELOPE FILTER
 INLET DUCTWORK & SORBENT SPILL PAN

DATE	REVISION	BY
10/11/83	1	PJA/TOR
10/11/83	2	TOR/PJA
10/11/83	3	TOR/PJA
10/11/83	4	TOR/PJA
10/11/83	5	TOR/PJA
10/11/83	6	TOR/PJA
10/11/83	7	TOR/PJA
10/11/83	8	TOR/PJA
10/11/83	9	TOR/PJA
10/11/83	10	TOR/PJA
10/11/83	11	TOR/PJA
10/11/83	12	TOR/PJA
10/11/83	13	TOR/PJA
10/11/83	14	TOR/PJA
10/11/83	15	TOR/PJA
10/11/83	16	TOR/PJA
10/11/83	17	TOR/PJA
10/11/83	18	TOR/PJA
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10/11/83	92	TOR/PJA
10/11/83	93	TOR/PJA
10/11/83	94	TOR/PJA
10/11/83	95	TOR/PJA
10/11/83	96	TOR/PJA
10/11/83	97	TOR/PJA
10/11/83	98	TOR/PJA
10/11/83	99	TOR/PJA
10/11/83	100	TOR/PJA

SCALE: NONE

DATE: 10/11/83

495

GAD FILE NO. 51355800

REVISION	DESCRIPTION	REVISION	DESCRIPTION
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

BASE PLATE DETAIL

ENVELOPE FILTER FIXED POINT

NOTES:

1. FOR OVERALL GENERAL ARRANGEMENT SEE DRAWING E/24-B50.
2. FOR GENERAL NOTES AND SPECIFICATIONS SEE DRAWING A/2X-001.
3. FOR SURFACE PREPARATION AND COATING SPECIFICATION SEE DRAWING A/2X-002. (PRIMER COAT ONLY, COATING NO. 01)
4. FOR WELDING SPECIFICATION SEE DRAWING A/2X-003.
5. FOR THE SHOP TOLERANCE SPECIFICATION SEE DRAWING A/2X-004.
6. FOR SUPPORT STEEL GENERAL NOTES AND SPECIFICATIONS SEE DRAWING A/2X-1.
7. FOR BILL OF MATERIAL SEE DRAWING A/2X-1.
8. ALL FIELD CONNECTIONS TO BE BOLTED FOR THE EASE OF ERECTION AND DISMANTLING.
9. WORK THIS DRAWING WITH E/2X-B01.

ELEVATION
ALONG COLUMN LINE "A"

ELEVATION
ALONG COLUMN LINE "2"

ITEM	DESCRIPTION	QUANTITY	UNIT	DESCRIPTION	QUANTITY	UNIT	DESCRIPTION	QUANTITY	UNIT	DESCRIPTION	QUANTITY	UNIT

GE Environmental Systems		
ENGINE TEST CELL #4		
CWS DIESEL ENGINE		
EMISSION CONTROL EQUIPMENT		
FULL FLOW ENVELOPE FILTER		
SUPPORT STEEL		
APPROVED BY	DESIGNED BY	DATE
SS9513	SS800	0
SCALE	NONE	

00180000 11/70

496

PLAN
TOP OF GRATING ELEV. 102'-10"
TOP OF STEEL ELEV. (-1')

NOTE: FOR PLATFORM FRAMING AND SUPPORT STEEL SEE DRAWING E/55-800.

POST CONNECTION
TO BACK OF CHANNEL

REMOVABLE
POST CONNECTION
TO BACK OF CHANNEL

NO.	DESCRIPTION	DESCRIPTION	DESCRIPTION
1	DESIGNED BY		
2	CHECKED BY		
3	APPROVED FOR DESIGN		
4	APPROVED FOR CONSTRUCTION		
5	APPROVAL DATE		

001 2 0 532 147 8

CAD FILE NO: 61355802

	DESCRIPTION	DESCRIPTION	
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
REVIEWED FOR ENGINEERING			
PROJECT MANAGER APPROVAL			
APPROVAL DATE:			
REVISIONS:			

Ch. 11, Sec. 222, § 2, 1990

[illegible][illegible]

NOTES:

1. WORK THIS DRAWING WITH DRAWING E/SS-201.
2. FOR BILL OF MATERIAL SEE DWG. A/SS-1.

✓

PLAN VI

ELEVATION

END FILE NO. 513FAB30

REVISION	DESCRIPTION	REVISION	DESCRIPTION
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

DESCRIPTION				1-8/30/92	DESCRIPTION	5-5/28/92	DESCRIPTION
				W24XB4	HOPPER FLANGE	ANN/PRO	DRAWN
				1'-8 1/2"	1'-8 1/2" WAS	T.RAY	
				1'-9"	1'-9" WAS	SK	
				1'-10"	1'-10" WAS		
				1'-11"	1'-11" WAS		
				1'-12"	1'-12" WAS		
				1'-13"	1'-13" WAS		
				1'-14"	1'-14" WAS		
				1'-15"	1'-15" WAS		
				1'-16"	1'-16" WAS		
				1'-17"	1'-17" WAS		
				1'-18"	1'-18" WAS		
				1'-19"	1'-19" WAS		
				1'-20"	1'-20" WAS		
				1'-21"	1'-21" WAS		
				1'-22"	1'-22" WAS		
				1'-23"	1'-23" WAS		
				1'-24"	1'-24" WAS		
				1'-25"	1'-25" WAS		
				1'-26"	1'-26" WAS		
				1'-27"	1'-27" WAS		
				1'-28"	1'-28" WAS		
				1'-29"	1'-29" WAS		
				1'-30"	1'-30" WAS		
				1'-31"	1'-31" WAS		
				1'-32"	1'-32" WAS		
				1'-33"	1'-33" WAS		
				1'-34"	1'-34" WAS		
				1'-35"	1'-35" WAS		
				1'-36"	1'-36" WAS		
				1'-37"	1'-37" WAS		
				1'-38"	1'-38" WAS		
				1'-39"	1'-39" WAS		
				1'-40"	1'-40" WAS		
				1'-41"	1'-41" WAS		
				1'-42"	1'-42" WAS		
				1'-43"	1'-43" WAS		
				1'-44"	1'-44" WAS		
				1'-45"	1'-45" WAS		
				1'-46"	1'-46" WAS		
				1'-47"	1'-47" WAS		
				1'-48"	1'-48" WAS		
				1'-49"	1'-49" WAS		
				1'-50"	1'-50" WAS		
				1'-51"	1'-51" WAS		
				1'-52"	1'-52" WAS		
				1'-53"	1'-53" WAS		
				1'-54"	1'-54" WAS		
				1'-55"	1'-55" WAS		
				1'-56"	1'-56" WAS		
				1'-57"	1'-57" WAS		
				1'-58"	1'-58" WAS		
				1'-59"	1'-59" WAS		
				1'-60"	1'-60" WAS		
				1'-61"	1'-61" WAS		
				1'-62"	1'-62" WAS		
				1'-63"	1'-63" WAS		
				1'-64"	1'-64" WAS		
				1'-65"	1'-65" WAS		
				1'-66"	1'-66" WAS		
				1'-67"	1'-67" WAS		
				1'-68"	1'-68" WAS		
				1'-69"	1'-69" WAS		
				1'-70"	1'-70" WAS		
				1'-71"	1'-71" WAS		
				1'-72"	1'-72" WAS		
				1'-73"	1'-73" WAS		
				1'-74"	1'-74" WAS		
				1'-75"	1'-75" WAS		
				1'-76"	1'-76" WAS		
				1'-77"	1'-77" WAS		
				1'-78"	1'-78" WAS		
				1'-79"	1'-79" WAS		
				1'-80"	1'-80" WAS		
				1'-81"	1'-81" WAS		
				1'-82"	1'-82" WAS		
				1'-83"	1'-83" WAS		
				1'-84"	1'-84" WAS		
				1'-85"	1'-85" WAS		
				1'-86"	1'-86" WAS		
				1'-87"	1'-87" WAS		
				1'-88"	1'-88" WAS		
				1'-89"	1'-89" WAS		
				1'-90"	1'-90" WAS		
				1'-91"	1'-91" WAS		
				1'-92"	1'-92" WAS		
				1'-93"	1'-93" WAS		
				1'-94"	1'-94" WAS		
				1'-95"	1'-95" WAS		
				1'-96"	1'-96" WAS		
				1'-97"	1'-97" WAS		
				1'-98"	1'-98" WAS		
				1'-99"	1'-99" WAS		
				1'-100"	1'-100" WAS		

GE Environmental Systems

FULL FLOW ENVELOPE FILTER

DATE: 1-8/30/92

SCALE: NONE

PLOT 1-16

REV: 1

FA-830

1

499

W24

10

11

CND FILE NO. 8137A831

REVISION	DESCRIPTION	REVISION	DESCRIPTION	DATE
DESIGNED BY				
CHECKED BY				
APPROVED FOR DESIGN				
APPROVED FOR CONSTRUCTION				
APPROVAL DATE

50

WELD PIPE NIPPLE
IN WALL AFTER ALL
HOLES IN BLOW PIPE
HAVE BEEN ALIGNED
OVER CENTERLINE OF
OPENING IN TUBE
SHEET - SEE DWG.
E/NA-838

ELEVATION

OMB FILE NO. 513FA832

REVISION	DESCRIPTION	DESCRIPTION	DATE
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

FOR GENERAL NOTES SEE E/FA-830.

<h2 style="text-align: center;">GE Environmental Systems</h2>			
<h1 style="margin: 0;">FULL FLOW ENVELOPE FILTER CASING DETAILS</h1>			
<div style="border: 1px solid black; width: 50px; height: 50px; margin: 0 auto; display: flex; align-items: center; justify-content: center; font-size: 24px; font-weight: bold;">1</div>			
Notes 1. This is a preliminary drawing. It is subject to change without notice. It is not to be used for construction or manufacturing purposes. It is for information only.	Model for Identification		Size
	Identification no.	Drawing no.-REV	Revision
Scale -	S9513	FA-832	2

PLOT 1-16

362 2747

CAD FILE NO. 513FAB33		DESCRIPTION		DESCRIPTION		DATE
DESIGNED BY						
CHECKED BY						
REVIEWED FOR DESIGN						
APPROVED FOR ENGINEERING						
APPROVAL DATE						

502

PLOT 1-12	
59513	FA-833
FULL FLOW ENVELOPE FILTER CASING DETAILS	
GE Environmental Systems	

NO.	DESCRIPTION	DATE	BY	CHK	APP
1	DESIGNED	1-8/20/82	SK		
2	REVIEWED	1-8/20/82	SK		
3	APPROVED	1-8/20/82	SK		
4	REVIEWED	1-8/20/82	SK		
5	APPROVED	1-8/20/82	SK		
6	REVIEWED	1-8/20/82	SK		
7	APPROVED	1-8/20/82	SK		
8	REVIEWED	1-8/20/82	SK		
9	APPROVED	1-8/20/82	SK		
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15	APPROVED	1-8/20/82	SK		
16	REVIEWED	1-8/20/82	SK		
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24	REVIEWED	1-8/20/82	SK		
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94	REVIEWED	1-8/20/82	SK		
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98	REVIEWED	1-8/20/82	SK		
99	APPROVED	1-8/20/82	SK		
100	REVIEWED	1-8/20/82	SK

PLAN

ELEVATION

END FILE NO. 5137A830

REVISION	DESCRIPTION	REVISION	DESCRIPTION
1	CHANGED	1	CHANGED
2	CHANGED	2	CHANGED
3	CHANGED	3	CHANGED
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96	CHANGED	96	CHANGED
97	CHANGED	97	CHANGED
98	CHANGED	98	CHANGED
99	CHANGED	99	CHANGED
100	CHANGED	100	CHANGED

APPROVED DATE

NO.	DESCRIPTION	DESCRIPTION	DESCRIPTION	DATE	DESCRIPTION	DATE	DESCRIPTION
1				1-10/26/83		0-8/8/82	
2				STRUTS WERE 5/16\"		ED	
3				THK. IN PLAN; STIFFENER WAS 5/16\"		LRAY	
4				THK. IN ELEVATION. ADDED BEND LINE LOCATION TO ELEVATION		SK	
5							DRAWN

GE Environmental Systems		
FULL FLOW ENVELOPE FILTER HOPPER DETAILS		
2		
DATE	DESIGNER	DATE
APPROVED BY	DESIGN NUMBER	REVISION
S9513	FA-836	1
PLOT 1-8		

505

8 | 7 | 6

PLAN

ELEVATION

OLD FILE NO: 513FA837

DESIGN	DESCRIPTION	DESCRIPTION	REVISION
DRAWN BY			
CHECKED BY			
APPROVED FOR DESIGN			
APPROVED FOR CONSTRUCTION			
APPROVAL DATE			

506

45 BLOW PIPE

44 BLOW PIPE

40 AIR PIPING MANIFOLD

CHG FILE NO. 515F A838

REVISION	DESCRIPTION	REVISION	DESCRIPTION
DESIGNED BY			
CHECKED BY			
REVISED FOR DESIGN			
APPROVED FOR CONSTRUCTION			
APPROVAL DATE			

1/8" MAXIMUM ALLOWABLE SWEEP
EITHER SIDE OF CENTERLINE

DETAIL
838

TRUE VERTICAL
DRILLED HOLES TO BE FREE FROM BURRS
ON THE INSIDE & OUTSIDE OF PIPE.
REMOVE ALL LOOSE TURNINGS,
TALINGS & CHIPS FROM INSIDE THE
PIPE. ALL HOLES MUST ALIGN VERTICALLY
WITH MAXIMUM ALLOWABLE TOLERANCE
AT 1/2" ANGULAR ROTATION
OFF VERTICAL CENTERLINE

SECTION
838

SECTION
838

AIR PIPE

AIR PIPE

AIR PIPE

AIR PIPE

FOR GENERAL NOTES SEE DRAWING D/FA-830.

GE Environmental Systems		
FULL FLOW ENVELOPE FILTER AIR PIPING DETAILS		
DATE	DESIGNER	DATE
APPROVED BY	DRAWN BY	REVIEWER
S9513	FA-838	1
SCALE: NONE PLOT 1-4		

DATE	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
11-13/16/92	AWW/PRD T. RAY	SK	DRAWN		
ADDED DIMENSIONS TO SECTION "1"					

507

CAD FILE NO. 513FA838

REVISION	DESCRIPTION	DESCRIPTION	REVISION
DESIGNED BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

8

7

8

SECTION
3
840

DETAIL
4
841

TRAILING EDGE OF THIS
VANE ONLY TO BE NOTCHED
AT EACH SIDE WALL

SECTION
6
840

CD FILE NO. 513FAB41

REVISION	DESCRIPTION	DESCRIPTION	DATE
DESIGNED BY			
CHECKED BY			
APPROVED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE			

510

JOB FILE NO. 513/AB42

REVISION	DESCRIPTION	REVISION	DESCRIPTION	REVISION	DESCRIPTION
DESIGNED BY					
CHECKED BY					
REVIEWED FOR DESIGN					
APPROVED FOR CONSTRUCTION					
APPROVAL DATE					

3 TUBE SHEET

VIEW

GE Environmental Systems			
FULL FLOW ENVELOPE FILTER TUBE SHEET			
3 & 4			
DATE FOR MODIFICATION		REV	
AUTHORIZATION NO.		DESIGNER	REVISION
S9513		FA-842	1
SCALE: NONE		PLOT 1-4	

DATE	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
1-5/30/92	ADDED 13/16\"/>								

511

5 TUBE SHEET

CAD FILE NO: 513FAB43					
REVISION		DESCRIPTION		DESCRIPTION	DESIGN
DRAWN BY					
CHECKED BY					
REVIEWED FOR DESIGN					
APPROVED FOR ENGINEERING					
APPROVAL DATE

REV	DESCRIPTION	DESCRIPTION	DESCRIPTION	1-9/18/92	DESCRIPTION	0-5/4/92	DESCRIPTION
				W. GREEN		JED	
				D. RAY		T. RAY	
				J. RILEY			
					ADDED 13/16" DIMEN.		
					TO LOCATE HOLES		
					ON SHEET		DRAWN
							</

GE Environmental Systems			
FULL FLOW ENVELOPE FILTER TUBE SHEET			
DATE	DESIGN FOR SUBMITTAL	DATE	
APPROVED BY	DRAWING NUMBER	SECTION	
S9513	FA-843	1	
SCALE - N.T.S. 1/4			

572

D

C

B

A

CAD FILE NO: 513FAB44

REVISION		DESCRIPTION	
DRAWN BY			
CHECKED BY			
REVIEWED FOR DESIGN			
APPROVED FOR ENGINEERING			
APPROVAL DATE

TYPICAL END PLATE WELDING

1 SECTION
844

DESCRIPTION	0-8/10/92	DESCRIPTION
	JED	
	T. RAY	
	<i>[Signature]</i>	
		ORIGINAL ISSUE

GE Environmental Systems		
FULL FLOW ENVELOPE FILTER OUTLET RAIN CAP		
7		
NOTICE <small>THIS IS A REPRODUCTION OF A GENERAL DRAFTING OF GEORGE ELECTRIC ENVIRONMENTAL SERVICES, INC. AND IS SUPPLIED FOR USE ONLY FOR AN APPROVED JOB. THIS DRAFTING IS THE PROPERTY OF AND CONTAINS CONFIDENTIAL, PROPRIETARY INFORMATION OF GEORGE ELECTRIC ENVIRONMENTAL SERVICES, INC. AND SHALL NOT BE REPRODUCED, USED, COPIED OR REPRODUCED IN ANY MANNER, OR IN ANY MANNER, WITHOUT THE WRITTEN CONSENT OF GEORGE ELECTRIC ENVIRONMENTAL SERVICES, INC. THIS DRAFTING SHALL NOT BE USED FOR CONSTRUCTION OR FABRICATION UNLESS IT IS CHECKED AND ISSUED FOR CONSTRUCTION.</small>	ISSUED FOR CONSTRUCTION	DATE
AUTHORIZATION NO.	DRAWING NUMBER	REVISION
S9513	FA-844	0
SCALE-	N.T.S.	C

1=12

OCT 20 1992 MFRG

513

END FILE NO. 513FAS45

REVISION	DESCRIPTION	DESCRIPTION
DRAWN BY		
CHECKED BY		
REVIEWED FOR DESIGN		
APPROVED FOR ENGINEERING		
APPROVAL DATE

NO.	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
1							
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12							

GE Environmental Systems

FULL FLOW ENVELOPE FILTER INSTRUMENT CONNECTION LOCATION

DATE FOR REVISION: _____

AUTHORIZATION NO. S9513 DRAWING NUMBER FA-845 REVISION 0

SCALE: NONE

PLOT 1-16

NOT TO SCALE

514

DETAIL

SECTION
1/2" (12) PLACES

CAD FILE NO: 513FAS48				
REVISION	DESCRIPTION	DESCRIPTION	DESCRIPTION	DESCRIPTION
DRAWN BY				
CHECKED BY				
REVIEWED FOR DESIGN				
APPROVED FOR ENGINEERING				
APPROVAL DATE

GE Environmental Systems					
<u>FULL FLOW ENVELOPE FILTER</u>					
<u>INSTRUMENT CONNECTION</u> <u>DETAILS</u>					
REVISED		DRAWN FOR CONSTRUCTION		DATE	
<p>THIS IS A PRELIMINARY DRAWING OF THE DESIGN OF THE FULL FLOW ENVELOPE FILTER. IT IS NOT TO BE USED FOR CONSTRUCTION OR FABRICATION OF THE FILTER. IT IS INTENDED TO SHOW THE GENERAL LAYOUT AND DIMENSIONS OF THE FILTER. THE FINAL DESIGN SHALL BE DETERMINED BY THE PROJECT ENGINEER.</p>					
APPROVED/DESIGNED BY:	DRAWING NUMBER:	REVISIONS:			
S9513	FA-846	0			
SCALE - NONE	E				

PLOT 1-8

OCT 30 1992 MF RO

515

TAB 11

**DOE/GETS TOPICAL REPORT
CHAPTER 5**

CHAPTER 5

Commensurate with Task 5, Integrated System Test.

Task 5.2, 5.3, & 5.4

Full Size Envelope Filter System Test

Test Planning and Accomplishments

A total of five test attempts were performed to operate the Full Size Envelope Filter during the time period from August 17, 1993 through September 3, 1993. Each of the first three test attempts failed to achieve CWS fuel engine operation sufficiently long enough to achieve useful test operation of the Envelope Filter. However, these test attempts did provide an opportunity to exercise the Envelope Filter system components. One experience of these test run attempts was the loss of the mass gas flow meter instrumentation and a substitution function by measurement of ductwork pressure drop.

Each failure to sustain operation of the engine with CWS fuel necessitated repeated servicing of engine components. Each repetition of this service reduced engine component reliability, and there became increasing concern that complete failure of engine operation could occur if this practice was continued.

In consideration of the risk of a total loss of engine operation capability and an end of the schedule for the operation of the test cell engine, a contingency plan for operation of the engine with pilot diesel fuel only, without CWS fuel, was executed. The plan included the addition of liquid carbon disulfide, CS_2 , to the pilot fuel to substitute for the sulfur which would have been contributed from the coal of the CWS.

One test, Test FULL 004, was successfully completed in accordance with this contingency plan for engine operation. Operation of the Envelope Filter Emissions Control system included use of copper oxide coated alumina precoat/sorbent particulate.

Another test, Test FULL 005, was also performed using the contingency plan pilot fuel with carbon disulfide engine operation. For this test, the Envelope Filter was planned to be operated using sodium bicarbonate sorbent injection into the filter inlet gas flow. However, as the test progressed, it became apparent that there was negligible SO_2 reduction and less than an anticipated filter pressure drop increase. Test operation was sustained for approximately two hours. Toward the end of the test run, the sorbent feed rate was increased by a gross increase of the rotary feeder speed. For a limited short period of operation in this manner, there was an indication of reduced filter outlet SO_2 concentration, as well as increasing filter pressure drop, suggesting that sorbent injection might just then be occurring. After shutdown of the engine, the Envelope Filter hopper was evacuated.

DOE/GETS TOPICAL REPORT CHAPTER 5

There was observed to be negligible particulate removal from the hopper confirming that virtually the entire test had been performed without any significant amount of sorbent injection. The sorbent storage bin level indicator produced obviously false information during the test, which made it impossible to diagnose this operation malfunction.

Test observations during the time of test operation indicated a filter gas flow of approximately 3000 ACFM which was consistent with the observation for successfully completed Test FULL 004. Also observed were filter inlet SO₂ and NO_x concentrations of 436 PPMV and 152 PPMV, respectively. These values were consistent with values determined during Test FULL 004.

In consideration of the very limited useful test results determined during Test FULL 005, these test results are not discussed in any greater detail in this report.

Following completion of Test FULL 005, the testing of the Full Gas Flow Envelope Filter was concluded in consideration of the complications of operating the engine at such low load and exhaust gas flow, and the very limited test results which could be determined.

Discussion of Results of Test FULL 004

Test FULL 004 was planned to be performed at an engine exhaust gas flow of approximately 4300 ACFM, based upon the maximum possible engine load using only pilot fuel. Copper oxide coated alumina was planned to be used at an injection concentration of 5 grains/ACF (180 lb/hour), corresponding to 317% of the stoichiometric requirement for SO₂ reduction. Ammonia injection was planned to be 4.0 lb/hour corresponding to 200% of the stoichiometric requirement for NO_x reduction. Ammonia injection into the engine exhaust gas was located as far^x as possible upstream of the Envelope Filter, just downstream of the bypass damper. Ammonia was injected into the exhaust gas flow through a distribution sparger to obtain effective mixing of the ammonia with the exhaust gas.

Preparations for the test included injection of 40 lbs. of Neutralite Aluminum Silicate precoat particulate into the filter inlet ductwork prior to the start of any gas flow to the Envelope Filter. An additional 40 lbs. of Neutralite was injected into the duct during low load engine warmup during very low gas flow into the Envelope Filter. Starting gas flow to the filter during low load engine warmup was a modified test procedure to avoid a sudden upset of back pressure imposed upon the engine if the bypass/operation damper was not opened until the engine was operating at maximum load and gas flow. The amount of Neutralite used for the test was in accordance with the manufacturer's recommendation for use to precoat fabric filters.

**DOE/GETS TOPICAL REPORT
CHAPTER 5**

After initial warm-up operation of the engine, Carbon disulfide was added to a pilot fuel mixing tank to supply fuel to the engine for Envelope Filter test operation. The amount of carbon disulfide added to the pilot fuel was calculated to produce an engine exhaust SO_2 concentration of 200 to 300 PPMV, as would be expected for full load CWS fuel engine operation. The amount of carbon disulfide mixed with the pilot fuel was based upon assumptions of operating engine load, engine exhaust gas flow, pilot fuel consumption, and pilot fuel sulfur content.

Results of Test FULL 004 are illustrated by seven graphs which are enclosed in Appendix 5. Each graph is a relationship of various test operating conditions and test results measurements during the time of the test run.

Graph 004A illustrates filter inlet gas flow as measured by the calibrated filter inlet duct pressure drop. The initial low gas flow was obtained during low engine load warm-up operation. Gas flow stabilized at approximately 3000 ACFM during the major portion of test operation. Graph 004A also illustrates filter pressure drop as a function of filter cleaning events. The relatively low magnitude of the filter pressure drop is a consequence of the low gas flow operating condition of the test. The test included three significant cleaning events. The first cleaning event was performed at test time 123 minutes from a cleaning initiation pressure drop of 2.1 IWG to a cleandown pressure drop of 0.4 IWG. The second cleaning was performed at test time 199 minutes resulting in a pressure drop change of 2.0 IWG to 0.5 IWG, and the third cleaning was performed at test time 238 minutes resulting in a pressure drop change from 1.7 IWG to 0.5 IWG. Other events of a change of filter pressure drop occurred at test times of 132 minutes and 170 minutes. Each incident resulted from an accidental short duration closing of the filter inlet/bypass damper. This caused gas flow to the filter to cease, and essentially zero filter pressure drop was indicated. In the case of the first incident, the filter media had just been cleaned. When gas flow was resumed, the pressure drop rise rate was not affected by the incident upset. However, the second incident occurred when the filter was operating at a 1.6 IWG pressure drop. It is suspected that some particulate deposition on the filter media was dislodged during the incident as the filter pressure drop did not restore to the pressure drop before the incident. When gas flow was resumed, the pressure drop rise was much more rapid than evidenced by intentional cleaning, indicating that a significant amount of particulate deposition remained on the filter media. After the incident and toward the end of the pressure drop rise, the rate of pressure drop rise became more similar to other intentional cleaning test results. A fourth intentional cleaning was performed at test time 264 minutes, but it is not considered significant because it was performed at a filter pressure drop of only 0.6 IWG, during decreasing gas flow prior to the end of engine operation.

All intentional filter media cleaning was performed by manual initiation and consisted of one cycle of cleaning all filter envelopes. Starting pulse air pressure was 94 PSIG and decreased to 71 PSIG at the end of a 1 second pulse duration. The time interval between pulses was 6 seconds.

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Precoat/sorbent particulate used for Test FULL 004 was copper oxide coated alumina. The sorbent source arbitrarily selected for test use was the Discovery Alumina vendor source.

Test operating conditions for sorbent operation are illustrated by Graph 004G. Test results are graphed from the beginning of gas flow to the Envelope Filter, although at a low gas flow rate during engine warm-up operation. The engine was at maximum load at test time 46 minutes. After equilibrium gas flow was attained, it was recognized that test gas flow was approximately 3000 ACFM, less than the anticipated test operating condition. Sorbent feed rate was decreased in accordance with this change, but a minimum control point for the rotary feeder prevented a sufficient decrease. Sorbent feed rate was decreased to 162 lb/hour, commensurate with a particulate concentration of 6.3 grains/ACF. This sorbent feed rate, at a gas flow of 3000 ACFM and a typical filter inlet SO_2 concentration of 445 PPMV, resulted in a sorbent stoichiometry of 232% for SO_2 removal.

Sorbent injection remained at this operating condition from test time 80 minutes to test time 102 minutes. Sorbent injection was turned off from time 102 minutes to time 115 minutes, but was resumed at the same injection rate from test time 115 minutes to 173 minutes. Sorbent injection was intermittent from time 173 minutes until 188 minutes, when it was resumed at the same rate based upon rotary feeder operation, until the end of the test at time 260 minutes. However, the sorbent level in the sorbent storage bin indicated that all sorbent was likely to have been consumed by test time 209 minutes. As indicated by Graph 004B showing filter inlet gas temperature, a sudden temperature increase verified the end of sorbent injection into the filter inlet gas flow.

Graph 004F illustrates that ammonia injection was started at test time 35 minute at a rate of 4.0 lb/hour, which was the requirement for 200% NO_x removal stoichiometry based upon expected gas flow and NO_x concentration operating conditions. However, once engine operation was stabilized at a reduced 3000 ACFM gas flow and a typical 100 PPMV NO_x concentration, instead of an expected 400 PPMV, ammonia was reduced to 2.0 lb/hour at time 62 minutes. At this adjusted operating condition, NO_x reduction stoichiometry was 600%. Ammonia injection was maintained at this operating condition until test time 130 minutes, when ammonia injection was turned off until time 140 minutes. Ammonia injection was resumed at the same rate until test time 222 minutes when ammonia injection was again turned off until test time 232 minutes. Ammonia injection was again resumed at the same rate until the end of the test at time 260 minutes.

Graph 004B illustrates Envelope Filter gas temperatures determined during the test. Filter inlet gas temperature was determined by a single thermocouple measurement into the filter inlet duct, downstream of the sorbent injection location. This thermocouple location is identified as TE-107 on GEESI Drawing S9513/FA-845. Filter outlet gas temperature was determined at two

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locations into the filter outlet duct, a short distance upstream of the filter discharge to the atmosphere. These thermocouple locations are identified TE-106 and TE-108 on Drawing FA-845. The graph of filter outlet temperature is the average of the two temperature measurements. The graph of filter casing gas temperature is an average of nine thermocouple measurements performed in a matrix within the filter casing, at thermocouple locations TE-109-1, 2, and 3, TE-110-1, 2, and 3, and TE-111-1, 2, and 3. Each of these locations was at the midpoint into the matrix of Envelope Filter envelopes and baffles.

Graph 004B shows that each of the three graphs of temperature characteristics are similar at the start of engine operation, falling in a range of 90 to 150°F as a result of the filter casing and ductwork heaters. From engine warm-up to test time 46 minutes when the engine attained maximum load, filter inlet gas temperature increased more rapidly than did the filter casing gas or the filter outlet gas. During maximum engine load operation, the filter inlet gas temperature increase rate was reduced, relative to the filter casing temperature and the filter outlet temperature. At the end of the test, filter inlet gas had attained a temperature of 750°F, while filter casing gas and filter outlet gas had attained reduced temperatures of 630°F and 590°F, respectively.

Several incidents which occurred during the test are illustrated by these temperature graphs. Short duration filter inlet gas temperature increases occurred each time the sorbent injection was stopped, at test times 102 minutes to 115 minutes, and at test times 173 minutes to 188 minutes. Also, abrupt decreases of temperature, especially obvious at the filter outlet gas temperature, occurred at test times 132 minutes and 170 minutes. These events coincide with the accidental closing of the bypass damper when gas flow to the filter was interrupted. Smaller decreases of filter outlet gas temperature are indicated at test times 123 minutes; 199 minutes and 238 minutes, when the filter was cleaned by cold ambient temperature air.

The significant difference between the filter inlet gas temperature compared to the filter casing and the filter outlet, is concluded to be indicative of incomplete heating of the mass of the filter casing and filter envelopes by the hot gas flow. This discrepancy can also be explained by insufficient effective thermal insulation on the filter casing.

A single gas analyzer system was operated connected to either the filter inlet gas flow or the filter outlet gas flow. During the switchover from one gas sampling location to the other, gas analyses were frequently confusing because of time delay, purging of sampling lines, and recalibration of the analyzer.

The gas analyzer system was started at test time 30 minutes, sampling gas at the filter outlet. Outlet sampling was continued until test time 84 minutes, but this operating gas analysis data is not useful because of increasing

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exhaust gas flow and variable sorbent and ammonia injection rates. Gas analyses were performed at the filter inlet, upstream of sorbent injection, but downstream of the ammonia injection, at two significant test time intervals, 84 minutes to 106 minutes and 162 minutes to 184 minutes. Another interval of filter inlet gas sampling was from 249 minutes until the end of the test, but this gas composition data is not meaningful because it occurred during decreasing gas flow before the end of engine operation.

All other gas analyzer operation was when connected to the filter outlet gas flow. The time intervals of significant filter outlet gas composition are from test time 106 minutes to time 162 minutes, and from 184 minutes to 249 minutes. Operation during these time intervals involved several variables of filter operation such as filter media pressure drop, sorbent injection operation, and ammonia injection operation.

Graph 004C illustrates SO_2 and NO_x gas composition measurements at the filter inlet and at the filter outlet during the test. Filter inlet SO_2 concentration is clearly identified by the two concentrations increasing to peak values of approximately 440 PPMV. This concentration exceeded typical CWS fuel engine operation at 200 to 300 PPMV because excessive carbon disulfide had been added to the pilot fuel used for engine operation during the test, in consideration of the assumed engine operating conditions. Filter inlet NO_x concentration is likewise clearly identified by concentrations of approximately 100 PPMV. This concentration was significantly less than typical CWS fuel engine operation at 400 to 700 PPMV. This discrepancy is concluded to have been caused by low load engine operation resulting in reduced engine exhaust gas temperature.

Filter outlet gas SO_2 concentration is shown by Graph 004C to be quite variable, ranging between concentrations of 190 and 270 PPMV during operation utilizing sorbent injection. Higher concentrations of SO_2 at the filter outlet are shown to occur when sorbent injection was stopped at test time 102 minutes to 115 minutes, and after test time 230 minutes when the supply of sorbent for injection was exhausted. The variation of SO_2 concentration within the range of 190 PPMV to 270 PPMV appears to be strongly related to the filter media pressure drop. As pressure drop increased and more sorbent was deposited on the filter media, filter outlet SO_2 concentration decreased because of increased contact time of the exhaust gas SO_2 with the sorbent. This relationship is more clearly illustrated by Graph 004G which includes superposition of sorbent feed rate, filter pressure drop, and SO_2 concentration.

Graph 004F illustrates that filter outlet NO_x concentration is best evaluated during several time intervals of increasing filter pressure drop at test times of 106 minutes to 125 minutes, 140 to 146 minutes, 185 to 200 minutes, and 200 to 220 minutes. During these time intervals, NO_x concentration ranged between 70 and 15 PPMV. In each case, the lower NO_x concentration coincides with greater filter pressure drop which caused improved opportunity

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for exhaust gas NO_x and injected ammonia to interact because of the catalytic property of the copper sulfate formed by the copper oxide sorbent and the exhaust gas SO_2 . Graph 004F also illustrates how filter outlet NO_x increased immediately during the time intervals when ammonia injection was stopped. However, cessation of sorbent injection did not result in any interruption of NO_x reduction because all copper sulfate previously formed remained deposited on the filter media and available for catalytic function.

Graph 004D recording of Hydrocarbons concentration illustrates filter outlet concentrations ranging between 320 to 430 PPMV, indicating some reduction of Hydrocarbon concentration by the reactivity of the sorbent. Graph 004D also illustrates CO concentrations ranging between 3000 to 3700 PPMV during the test. These variations do not show any predictable relationship to filter inlet or filter outlet sampling locations, or to any of the filter operation variables of pressure drop, sorbent injection, or ammonia injection.

Graph 004E illustrates CO_2 and O_2 concentration measurements during the test. These two measurements were very consistent at values of 6.5% and 11.0% by volume, respectively. These measurements were also not affected by filter inlet or filter outlet sampling locations or by any of the variables of filter operation.

Another diagnostic performed during the test was isokinetic sampling of the Envelope Filter particulate effluent. This testing was performed at sampling test port PDT-104. Test results reflected the composite of the entire test duration, including the variation of all test operating conditions.

Envelope Filter Performance

Envelope Filter operation with the use of copper oxide/alumina sorbent/precoat particulate injection demonstrated a reduction of SO_2 , NO_x , and some small reduction of Hydrocarbon gases. A reduction of SO_2 concentration, from 440 PPMV measured at the filter inlet to a range of 190 to 270 PPMV measured at the filter outlet, corresponds to a reduction efficiency of 57% to 39%. This performance was less than an expected 90% reduction which was based on previous program achievements. However, the operation of the Envelope Filter at gas temperature conditions which did not exceed an average of 650 F within the filter casing where the reactions occurred, is judged to be a possible explanation for the reduced performance.

NO_x reduction, from a concentration of 100 PPMV at the filter inlet to 70 to 15 PPMV at the filter outlet, reflects a NO_x reduction of 30% to 85%. This performance approaches an expected 85% reduction and would be expected to be improved if carried out at higher gas temperature within the filter casing.

Some Hydrocarbon gas reduction was realized based upon a filter inlet concentration of 500 PPMV and a filter outlet concentration of 320 to 430 PPMV. This performance reflects a reduction efficiency ranging between 36% to 14%.

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Operation of the Envelope Filter with copper oxide/alumina precoat/sorbent injection did not affect CO, CO₂, or O₂ concentrations.

The test measurement to determine particulate escape from the Envelope Filter resulted in an average particulate escape concentration of 0.0249 grains/ACF of filter outlet gas flow. This particulate escape did not result in any visible particulate emissions from the Envelope Filter.

Assuming that the Envelope Filter inlet gas flow was constant at 3000 ACFM during the entire test, projecting this gas flow to the reduced gas temperature filter outlet gas flow, and integrating the filter inlet particulate concentration based upon sorbent/precoat feed rate, CWS ash, and Neutralite precoat, results in an average particulate collection efficiency of 99.60%. This performance is a significant improvement from the test results which were obtained during the single cylinder CWS fuel engine hot gas testing. This test result confirms an expected 99+% collection efficiency, and also confirms the filter media selected for use as well as the design and construction of the filter media attachment to the filter envelopes and the installation of the filter envelopes in the filter casing.

A P P E N D I X 5

DOE/GETS CWS FUEL DIESEL EMISSIONS CONTROL TEST FULL 004 9/2/93

CUO/AL2O3 (DISCOVERY) SORBENT
CS2/PILOT FUEL ENGINE OPERATION

GRAPH 004A

* FIGURE 5-1 *

DOE/GETS CWS FUEL DIESEL EMISSIONS CONTROL TEST FULL 004 9/2/93

CUO/AL2O3 (DISCOVERY) SORBENT
CS2/PILOT FUEL ENGINE OPERATION

GRAPH 004B

* FIGURE 5-2 *

DOE/GETS CWS FUEL DIESEL EMISSIONS CONTROL TEST FULL 004 9/2/93

CUO/AL2O3 (DISCOVERY) SORBENT
CS2/PLOT FUEL ENGINE OPERATION

GRAPH 004C

DOE/GETS CWS FUEL DIESEL EMISSIONS CONTROL TEST FULL 004 9/2/93

CUO/AL2O3 (DISCOVERY) SORBENT
CS2/PILOT FUEL ENGINE OPERATION

GRAPH 004D

* FIGURE 5-4 *

DOE/GETS CWS FUEL DIESEL EMISSIONS CONTROL
TEST FULL 004 9/2/93

CUO/AL2O3 (DISCOVERY) SORBENT
CS2/PILOT FUEL ENGINE OPERATION

GRAPH 004E

DOE/GETS CWS FUEL DIESEL EMISSIONS CONTROL TEST FULL 004 9/2/93

CUO/AL2O3 (DISCOVERY) SORBENT
CS2/PILOT FUEL ENGINE OPERATION

GRAPH 004E

* FIGURE 5-5 *

DOE/GETS CWS FUEL DIESEL EMISSIONS CONTROL TEST FULL 004 9/2/93

CUO/AL2O3 (DISCOVERY) SORBENT
CS2/PILOT FUEL ENGINE OPERA

GRAPH 004F

* FIGURE 5-6 *

DOE/GETS CWS FUEL DIESEL EMISSIONS CONTROL TEST FULL 004 9/2/93

CUO/AL2O3 (DISCOVERY) SORBENT
CS2/PILOT FUEL ENGINE OPERATION

GRAPH 004G

**DATE
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7/21/94

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