Multi-Stage Collector (MSC™) Proof-of-Concept Pilot Design and Evaluation.

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1.0 ABSTRACT

The new MSC™ technology provides optimum combination of single- and two-stage electrostatic precipitation augmented by a barrier filtration. This arrangement ensures that essentially all dust would be detained within the collector.

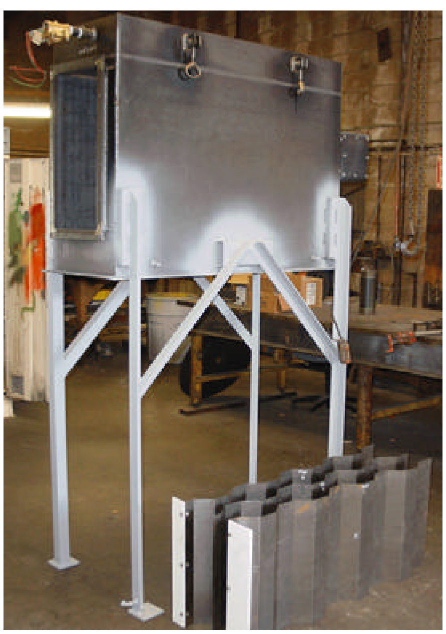
The operation of the MSC™ is virtually independent of the collected material electrical resistivity, hence its application will be especially beneficial when electrical resistivity of material either exceeds 10^{11} or is less than 10^{4} Ohm-cm. This technology will be even more beneficial when the collected material consists of sub-micron particles (PM 2.5) or when emissions must attain "super-clean" (for example the "Vision 21" or = 0.005 lb/MBtu) levels.

The paper will present details of the proof-of-concept demonstration pilot design. Results of its preliminary evaluation and future development work will be discussed.

2.0 INTRODUCTION

Devices currently used in industry to remove particulate matter from various process gases include Electrostatic Precipitators (ESP) and Fabric Filters (FF). While these devices are widely used, they have a number of shortcomings. The current research addresses these shortcomings through the development of a new concept for particulate removal and control; the Multi-Stage Collector (MSC™).

Figure 1. MSC™ Proof-of-Concept Pilot



The MSC™ collector is a patented process (Krigmont, US Pat. ? 6,524,369 [1]) that entails a unique integration of both electrostatic precipitation and barrier filtration. The MSC™ concept overcomes not only the shortcomings of conventional ESP's and FF's, but is also technically superior to hybrid ESP/FF concepts currently under development. Subsections below will provide the technical background on why the MSC™ concept is a major technological advance in particulate collection.

To date, (1) a patent has been issued for the MSC™ concept (Krigmont. US Pat. ? 6,524,369), (2) CFD calculations have been performed investigating the flow patterns through the MSC™ device, and 3) a pilot/bench-scale MSC™ particulate collector has been designed and fabricated (Figure 1). The Proof-of-Concept phase involves the development of the MSC™ concept through an experimental study using this bench/pilot-scale MSC™ device.

Successful development of the MSC™ particulate collector will provide industry with a technologically advanced particulate removal device. Compared to current technologies, the MSC™ provides:

- a more compact particulate collector
- a more energy-efficient particulate collector
- a device with a high particulate removal efficiency (99.99%) for all particle sizes including fine particles

- a particulate collection device whose collection efficiency is independent of the particulate characteristics (i.e., size, electrical resistivity).

3.0 BACKGROUND

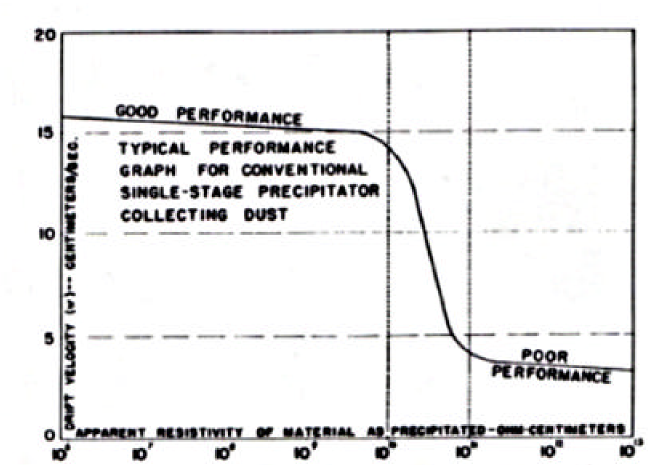
As mentioned previously, the most widely used methods to remove particulate matter from industrial process streams are ESP's and FF's. In addition, there are a number of developments under way of hybrid devices integrating ESP/FF concepts. To better understand why the MSC™ concept is technically superior to current ESP and FF systems as well as the current hybrid technologies, it is appropriate to briefly review how each works along with delineating their shortcomings.

3.1 ELECTROSTATIC PRECIPITATION

A typical electrostatic precipitator incorporates two zones:

- The charging zone, where the dust or aerosol particles are being charged, and
- The collecting zone, where the charged particles are being separated and transferred from the gas stream to a collecting electrode with subsequent removal into the collecting or receiving hoppers.

Figure 2. "Conventional" Precipitator Migration Velocity Relationship



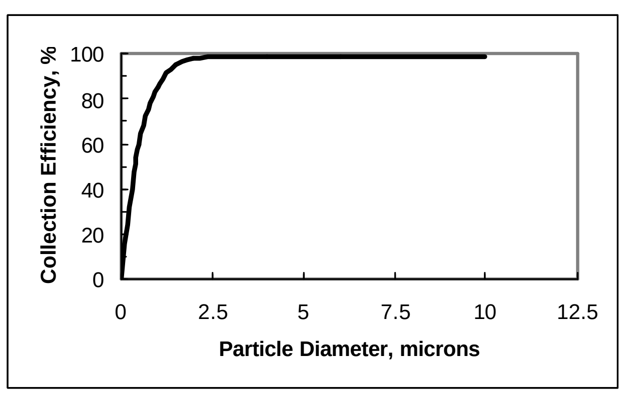
The arrangement of these zones led to two typical precipitator design concepts: (i) a conventional electrostatic precipitator where both zones are combined in a single-stage, and (ii) so called two-stage design where these zones are separated.

With high resistivity ash, a voltage drop occurs across the ash layer on the collection plates. This can cause an electrical breakdown resulting in a "back corona" or sparking at the surface of the dust layer causing re-entrainment

This back corona also results in a "bi-polar" charge. When this happens, the particles that are repelled, or re-entrained, from the collecting surfaces are carrying an opposite charge from the main inventory of entrained particles. None of the conventional ESP, or the hybrid devices under development, can deal effectively with these bi-polar particles.

In the case of the low-resistivity dust, a somewhat similar process takes place; however, due to an entirely different phenomena. Low resistivity dusts are known to quickly discharge; thus, they are repelled back to the gas stream nearly instantly upon contacting the collecting plates irrespective of their polarity. Viewed as a statistical phenomenon, therefore, particles of dust tend to move in a zig-zag fashion between the plane of the discharge electrodes and the collecting electrodes as the gas entrains such particles along the collecting path. The zig-zag movement is a phenomenon which is associated with both high- and low-resistance dusts.

Figure 4. ESP Collection Efficiency



Because of the zig-zag phenomenon, the effectiveness of dust collection is obviously reduced and hence the performance of a dust-collecting or dust-arresting assembly is substantially lower for high-or low-resistance dusts than dusts with normal electrical resistivity. The fact that ESP performance depends on the resistivity of the dust is one of the major shortcomings of this device. Figure 2[2] illustrates the effect of particle resistivity on performance of a conventional ESP. Below a resistivity of 10^{10} ohm-cm, the performance of the conventional ESP is generally good. Above 10^{10} ohm-cm, the performance degrades. Sproull[2] investigated a special two-stage electrostatic precipitator for high resistivity dusts collection application. His laboratory device showed that for high resistivity dust, the two-stage design offers certain advantages at least based on the reported laboratory data.

The energy requirements for operation of an ESP consist mainly of 1) electricity demand for fan operation, 2) electric field generation, and 3) cleaning. It is evident that separation energies are larger for a given mass of fine particles because of their much greater dispersion. Dr. White[3] calculated power in watts expended to separate charged particles of various sizes from an air stream of 100,000 cfm at a particle loading of 1 gr/ft^3. A power of about 500 W is needed to remove one-micron particles and only 5 W for the 10-micron particles. To summarize, ESP's power consumption ranges from 25 to 100 W/kacfm, with 40 W/kacfm being typical for the two-stage precipitators.

In general convention, ESP will have a collection efficiency of nominally 99.5-99.9%. In addition, this collection efficiency is dependent on particle size. Figure 3 shows the typical collection efficiency as a function of particle size for an ESP. As can be seen, below 1-2 µm the collection efficiency degrades.

3.2 FABRIC (BARRIER) FILTERS

The electric power industry, as well as industrial user companies, are looking for ways to upgrade their particulate control equipment. One approach would be to replace the existing under-performing ESP with Fabric Filters (or barrier filters). The Fabric Filter is generally accepted as an alternative to precipitators for collecting fly ash from the flue gas. Conventional designs can be categorized as low-ratio baghouses (for example, reverse-gas and shake-deflate) and relatively high ratio ones, so called pulsejet baghouses. Fabric Filters generally operate at **F**iltration **V**elocities (FV) of 0.76 to 1.27 centimeters per second (1.5 to 2.5 ft/min), also defined as air-to-cloth ratio or volumetric flow rate of flue gas per unit of effective filter area (cubic feet of flue gas flow/min/square foot of filtering area). The pulsejet baghouses, on the other hand, generally operate at 1.52 to 3.05 centimeters per second (3 to 6 ft/min).

Fabric Filters generally have very high collection efficiencies (greater than 99.9%) and the collection efficiency is largely independent of fly ash properties. However, because of their low filtration velocities, they are large, require significant space, are costly to build, and unattractive as replacements for existing precipitators. Reducing their size by increasing the filtration velocity across the filter bags usually results in unacceptably high pressure drop and reduced collection efficiency. There is also potential for "blinding" the filter bags – a condition where particles become embedded deep within the filter and cannot be "cleaned".

A typical pulsejet baghouse includes a number of individual bags or filtration tubes about four to six inches in diameter, eight to twenty feet long, and are mounted within and suspended from a tube sheet. The particulate dust is collected on the outside surfaces of the bags while the clean flue gas passes through the porous media to the inside, where it exits through the top of the bags into a clean air plenum and subsequently out the stack. Cages are installed inside the bags to prevent them from collapsing during the normal filtration process.

The other type of Fabric Filter is the reverse gas design. For a utility application, the bags will be nominally 1-foot in diameter and 30-feet long. The dust-laden gas flows from the inside of the bags where the dust is removed, with clean gas flowing on the outside of the bags. Rather than a pulse of compressed air which is used to clean the pulsejet designs, the reverse gas uses a higher volume of cleaned flue gas that flows through the bags in a reverse direction (i.e., inside to outside).

Because of the small bag spacing of the pulsejet units and forward filtration through the two rows of bags adjacent to the row being cleaned, much of the dust that is removed from one row of bags is simply recollected on the adjacent rows of bags. Thus, only the very large agglomerates of dust reach the hopper. This phenomenon of re-dispersion and collection of dust after bag cleaning is a major obstacle to operating 'conventional' baghouses at higher filtration velocities.

3.3 HYBRID PARTICULATE COLLECTORS

The traditional ESP suffers from a relatively low collection efficiency, particularly for fine particulates, and its performance depends on the electrical resistivity of the particulate that is being collected. The Fabric Filter, while exhibiting a much greater collection efficiency that is largely both size and property independent, provides a rather large pressure drop and is physically a large device.

In an effort to overcome the above deficiencies (i.e., increasing collection efficiencies without a corresponding increase in pressure drop), a number of efforts have been, and are, underway to develop hybrid particle collectors. These hybrid devices attempt to integrate electrostatic and barrier filtration into a single device or system. The MSC™ device, which is the subject of the current proposal, falls into this hybrid category. That said, it is important to discuss why the MSC™ concept is technically superior to other hybrid concepts.

The hybrid particulate collection concepts of interest include:

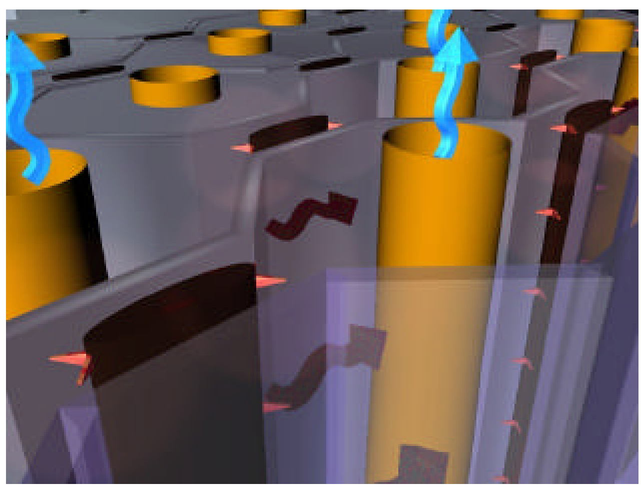
- electrostatically enhanced Fabric Filter
- EPRI's COHPAC-1 and COHPAC-2 systems
- UNDEERC Hybrid Collector (Advanced Hybrid™)
- MSC™

3.4 MSCÔ PARTICULATE COLLECTOR

The principal objective of the MSC™ design is to substantially improve fine particulate collection by combining electrostatic charging - collection and filtration processes not only by separating zones for particles charging and collecting, but, by providing new, unique collector design with improved efficiency to collect fine dust particles independent of their electrical properties. Figure 4 presents an artist's rendition of a conceptual MSC™.arrangement.

The MSC™ offers a uniquely compact concept. Each of the multiple stages utilizes an upstream stage comprised of a conventional electrostatic precipitator, followed by a downstream zone of parallel surfaces creating uniform electric field, followed by yet another sub-stage, which incorporates barrier filter conductive surfaces which provide a uniform electric field. By providing continuously repeated stages in series, the downstream zones effectively charge and collect the particles that are either uncollected or reentrained and collect those particles after they have been charged.

Figure 5. MSC Arrangement (Artist's Rendition)



In the MSC™, particles are deposited onto the **B**arrier **F**ilter **E**lement (BFE) by two mechanisms, electrostatic and diffusional deposition, that act simultaneously. Collection by diffusion occurs as a result of both fluid motion and the Brownian (random) motion of particles. Diffusional collection effects are most significant for particles less than 1 micrometer (μm) in diameter. Another collection mechanism, direct interception, occurs when a particle comes within one particle radius of an obstacle. The path that the particle takes can be a result of inertia, diffusion, or fluid motion.

On one hand, electrostatic deposition is effective for relatively large particles, but it is quite ineffective for the ultra-fine ones because their charging probability in the corona field is too low. However, the diffusional collection efficiency of particles on fibers is high for small particles but low for the larger ones. Therefore, the simultaneous diffusional-electrostatic collection is a useful technique for efficient filtration of particles below 0.1 μm.

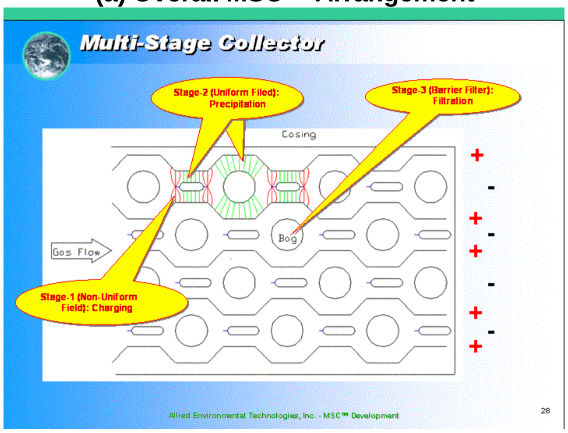
The MSC™ assembly (Figure 5a) is made up of discharge electrodes placed between oppositely charged electrodes. The discharge electrodes are followed by **B**arrier **F**ilter **E**lements (BFE) located in the wide zone placed between the collecting electrodes, the surface of the BFE can be made conductive. The corrugated plates are held at a first electrical potential while the discharge electrodes and the conductive surface of the BFE's are held at a second electrical potential. Both the flat sides of each of the discharge electrodes, corrugated plates and the surfaces of the BFE form collecting surfaces where the electric field is relatively uniform.

The surfaces of the conductive BFE's are formed with electric field forming parts that may be suitably rounded and convex in the direction of the collecting electrode (Figure 5b). The corrugated plate collecting electrodes are formed with narrow and wide sections to accommodate both the discharge electrodes and BFE's. By using an electrode with a cross-section that is relatively wide, a uniform electric field can form in the region of the center of the electrode, and a non-uniform field of high intensity can form at the sharp leading and/or trailing edge.

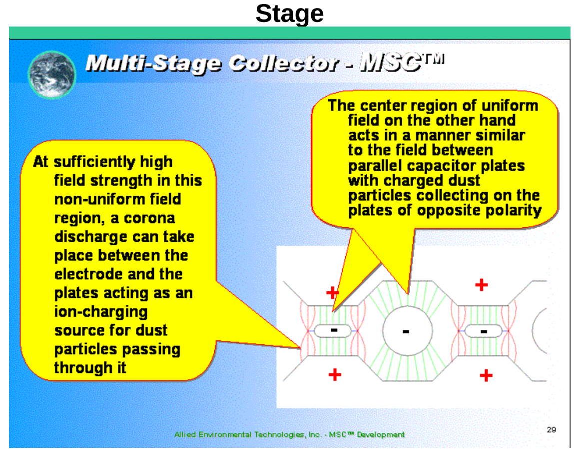
At sufficiently high field strength in this non-uniform field region, a corona discharge can take place between the electrode and the plates acting as an ion-charging source for dust particles passing through it. The center region of uniform field on the other hand acts in a manner similar to the field between parallel capacitor plates with charged dust particles collecting on the plates.

Figure 6. MSC™ Details

(a) Overall MSC™ Arrangement



(b) Phenomena Occurring in a Single MSC™ Stage



The dust particles around the discharge electrodes (i.e., in the regions of the corona-generating points), which were charged to negative polarity, are caught by the collecting electrode. Meanwhile, dust particles near the corrugated collecting plate electrode, which have been charged to a positive polarity by the positive ions resulting from reverse ionization, are conveniently collected by the uniform field-forming part of the discharge electrode and the conducting surfaces of the BFE's. Thus the MSC™ collector can deal with bi-polar charged particles

The spacing between the discharge points (corona sources) and collecting surfaces are different, wider in the charging or corona generating zones and narrower in the collecting ones where a uniform high voltage electric field is required. This feature allows for the use of a single high voltage power source for all electrostatic fields (in all zones). A high voltage electric field of an adjustable (variable) frequency and/or alternating polarity could also be applied to the dust arresting assembly to further improve collecting efficiency of bipolar charged aerosol onto the surfaces of both plates, thus, substantially increasing the effective collecting area. It should be noted that all collection surfaces can be cleaned in a conventional manner such as by rapping, polarity reversal, or by other means.

Another unique feature is that the MSC™ is engineered in such a way that the BFE and the DE are grounded while the parallel corrugated electrodes are suspended from the insulators. By virtue of having the BFE's at the same potential as the DE's, the MSC™ design completely eliminates any potential sparks from the DE toward the BFE, thus eradicating any chances of causing fires and/or puncturing holes in the porous barrier media. Hence, whether the MSC™ is powered by a "conventional" or an alternating power source, the BFE's remain protected from any sparks from the DE irrespective of dust concentrations .

As is apparent from the above discussion, the MSC™ design overcomes most of the issues associated with hybrid collectors and should provide a compact, high efficiency and energy efficient device.

4.0 EXPERIMENTAL WORK

4.1 TECHNICAL OBJECTIVES

The overall technical objective of the Proof-of-Concept (POC) research project is to experimentally demonstrate at a small pilot-scale the advantages of the MSC™ concept over conventional particulate collectors (i.e., ESP, Fabric Filters, and other hybrid ESP/FF collectors). Specific questions to be answered during the POC research include:

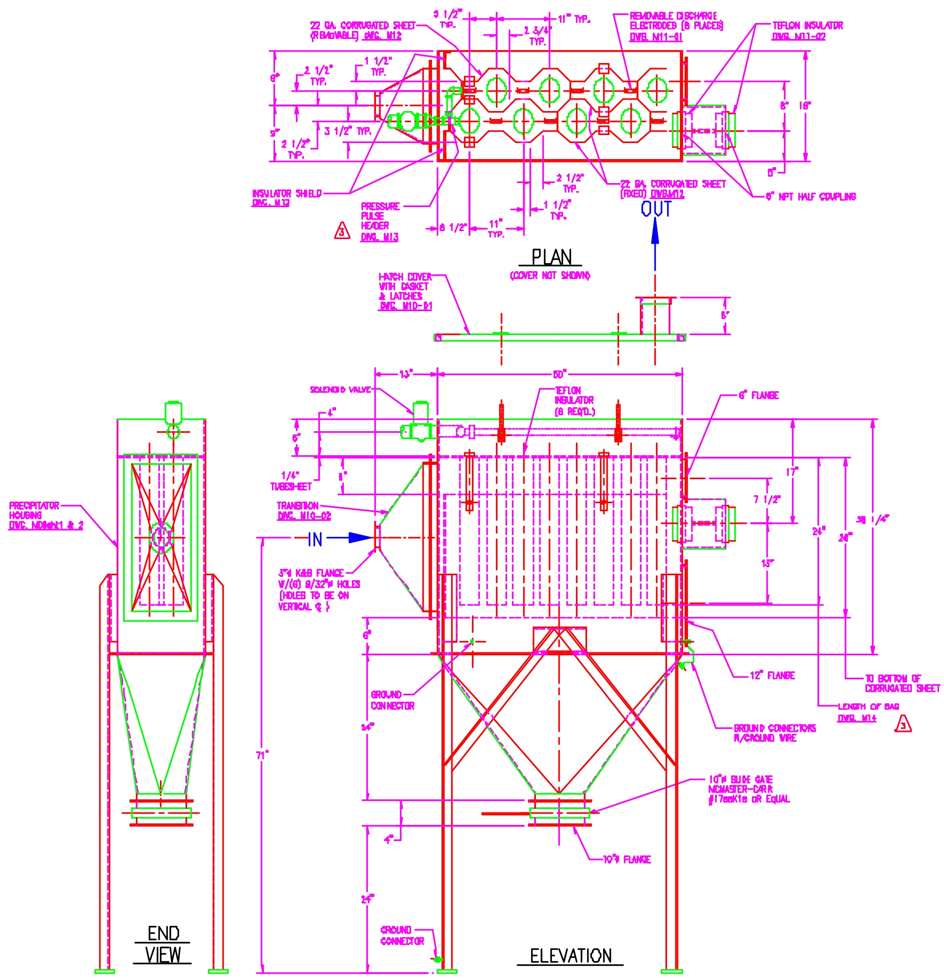
- Does the MSC™ collector exhibit higher overall collection efficiency than conventional and developing hybrid collectors (i.e., collection efficiency >99.9%)?

- Is the MSC™ collection efficiency independent of ash resistivity?
- Is the MSC™ collection efficiency of fine particles better than conventional technology?
- Can the overall size of the MSC™ collector (i.e., Face Velocity) be markedly smaller than conventional technology, for a given collection efficiency?
- Can the MSC™ collector collect bipolar charged particles?
- Is the MSC™ collector immune to back corona?

4.2 DEMONSTRATION MSC™ PILOT

The Proof-of-Concept (POC) Research Phase will be done using a working prototype of the MSC™ (**D**emonstration **MSC**, or **DMSC**) that was designed to operate with the **F**ace **V**elocity (FV) in the 3.59 – 28.73 ft/min (0.02-0.15 m/s) range. DMSC was designed to obtain sufficient data for scale-up of the MSC™ concept. Design of the equipment was based on computer simulations, engineering calculations, and previous conceptual analyses. Figure 6 presents a schematic of the DMSC design. The DMSC consists of two (2) rows of barrier filters (bags) four (4) bags each for a total of eight (8) bags and three (3) collecting corrugated plates.

Figure 7. Demonstration MSC™



Its design data are presented in Table 1Table 1. At this scale, it will be possible to satisfy most of the important dimensions such as electrode spacing, **B**arrier **F**ilter **E**lement (BFE) diameter and spacing in a row. The most important dimensions to simulate are the discharge point-to-plate, parallel surfaces spacing in the narrow and wide zones and discharge point-to-BFE spacing, as well as the BFE diameter so these dimensions are similar to that of a full-scale unit. This approach simulates the geometric arrangement in a full-scale MSC™ and would facilitate testing the effect of cleaning adjacent BFE's. Furthermore, testing at different **F**ace **V**elocities (FV) can easily be accomplished by either removing BFE's or by blocking a gas passage. Sight ports are installed at strategic locations to facilitate visual inspection and video monitoring of the BFE's, discharge and corrugated plate electrodes during normal filtration and cleaning cycles. The DMSC vessel will be heat-traced and insulated for precise temperature control.

4.3 COMBUSTION FACILITY

The pilot MSC™ unit is set up in Fossil Energy Research Corp.'s (FERCo) combustion research laboratory in Laguna Hills, California. FERCo's pilot-scale combustor will be used to supply ash laden flue gas to the MSC™ pilot unit. This facility has been used for a wide variety of studies ranging from fundamental studies of the measurement of N_2O in combustion systems and SNCR chemistry, to the characterization of dry SO_2 removal processes. A schematic of the overall pilot-scale facility used for these tests is shown in Figure 8.

Table 1. Demonstration MSC™ Design Data

UNIT ID === >			Simulated Performance Data 250,000 Btu/hr	
			English	Metric
Design Inlet Conditions	Temperature	Deg. F - C	300.0	148.9
	Flue Gas Moisture	%	8.50	8.50
	Flue Gas Flow, dry	cfm - Nm^3/s	33	0.02
	Flue Gas Flow, actual	acfm - m^3/s	60	0.03
Barrier Filter Data	**Gas Passages per Compartment**	**No.**	**2**	**2**
	Barrier Filter Diameter	**inch - cm**	**4.00**	**10.16**
	Barrier Filter Length	**ft. - m**	**2.00**	**0.61**
	No. of BF's per Gas Passage	**No.**	**4**	**4**
	Filtration Velocity (FV)	ft/m - m/s	3.59	0.02
ESP Zones Data	Electrical Gap in Charging Zone	in - mm	1.50	38
	Electrical Gap in Uniform Field Zone	in - mm	1.00	25.40
	Electrical Gap in Barrier Filter Zone	in - mm	1.00	25.40
	Effective Length of Collecting Electrodes	ft. - m	4.26	1.30
	Number of DE per Gas Passage	No.	4	4
	Effective Height	ft. - m	2.00	0.61
Design Details	Effective Electrode Collecting Area in ESP Zones per Compartment	sq. ft. - m2	39.40	3.66
	Total Collecting Area per Compartment	sq. ft. - m2	56.16	5.22
	Total Collecting Area	sq. ft. - m2	56.16	5.22

The pilot-scale combustor fires natural gas with a Hauck Model 215 burner into a water cooled combustion section. The gas temperature leaving the burner section is controlled by the firing rate and water-cooled inserts; the air and natural gas flow to the burner and combustion section are controlled with valves and monitored with rotameters. Ash can be pneumatically injected into the combustion section through a water cooled probe. The ash is metered with a calibrated screw feeder and pulled into the transport line through an educator; the motive air is monitored with a rotameter.

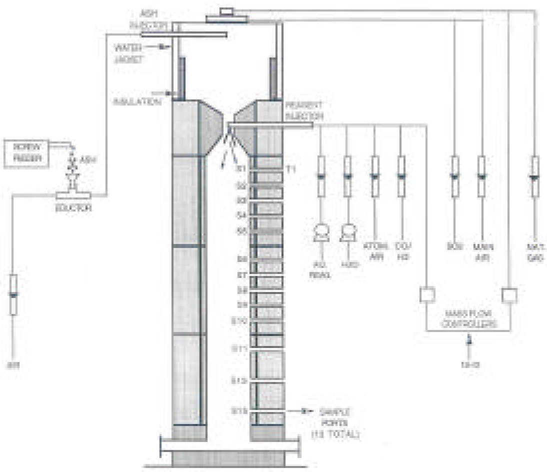
Various other chemicals, such as liquid urea and ammonium hydroxide solutions, can be injected into the combustion products through a single water-cooled injector located in the venturi section, depending on the nature of the study. The venturi section has a three-inch diameter throat, with the exit increasing to match the six-inch diameter test section.

The test section is nominally 90 inches long from the injection section exit to the combustor exit. Sampling ports are located every six inches along the test section. Samples can be withdrawn at these various axial positions in the test section; each different axial location corresponding to a different residence time. A suction pyrometer is used to determine the gas temperature in the test section. The combustor is fabricated from a castable refractory nominally five inches thick along the test section. These castable refractory sections are wrapped with four and one-half inches of Kaowool ceramic fiber insulation; the complete unit is housed in a steel casing. The facility is supported by a flue gas analysis system. For the proposed program, the combustor will be used as a combustion product source for the pilot MSC™ unit. Fly ash from selected utility boilers will be pneumatically injected into the natural gas combustion products as shown in Figure 7.

The pilot MSC™ unit has been fabricated (Figure 1) and is currently being set up in FERCo's facility.

To characterize the performance of the MSC™ collector, particulate measurements (both loading and size) will be made at the inlet and outlet of the pilot unit. The majority of the measurements will be made using a laser-based Malvern instrument.

Figure 8. Pilot-Scale Apparatus: Combustor, MSC™ and Ancillary Equipment



4.4 EXPERIMENTAL WORK

4.4.1 Laser Diffraction

The Proof-of-Concept effort will utilize Laser Diffraction (LD) for measurement of particle size distribution and concentration. A Malvern 2600C laser diffraction particle sizer is available to provide line-of-sight measurement of particle size distributions and particle concentration. This well established method of characterizing particles provides a relatively rapid and consistent measurement with little user controls.

4.4.2 Data Validation

To confirm the laser based measurements, selected measurements of the particulate loading will be made using EPA Method 17 and a cascade impactor will be used to determine the particulate particle size.

The testing will be structured to investigate the following MSC™ parameters:

- Electrical field strength
- Electrical polarity
- Face velocity (in the pilot MSC™ unit, the FV is changed by blanking off selected barrier filter elements)
- Ash resistivity (i.e., ash type)
- Ash loading
- Ash Type (Eastern Bituminous, PRB)

The ash loading will be varied to cover ash loadings for coals with ash contents ranging from 8% to 25%. Each test will involve determination of ash loading and size distribution at the inlet and outlet of the MSC™ unit. This will allow the overall collection efficiency to be determined as well as determining the collection efficiency as a function of particle size.

4.5 COMPUTATIONAL FLUID DYNAMICS (CFD) MODELING

To verify the gas flow inside the MSC, the Computational Fluid Dynamics (CFD) model was built based on the geometry shown on Figures 1 and 7.

Figure 9. CFD Simulation. Center Plane Gas Flow Distribution

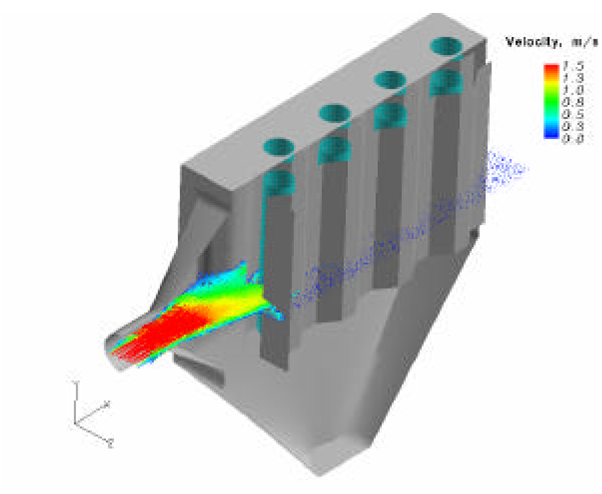


Figure 10. CFD Simulation. Bags Exit Gas Flow

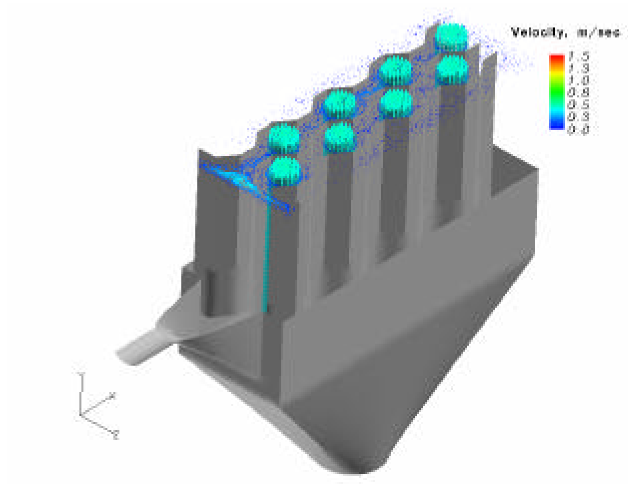


Figure 11. CFD Simulation. Center Plane Gas Flow Distribution. Top View

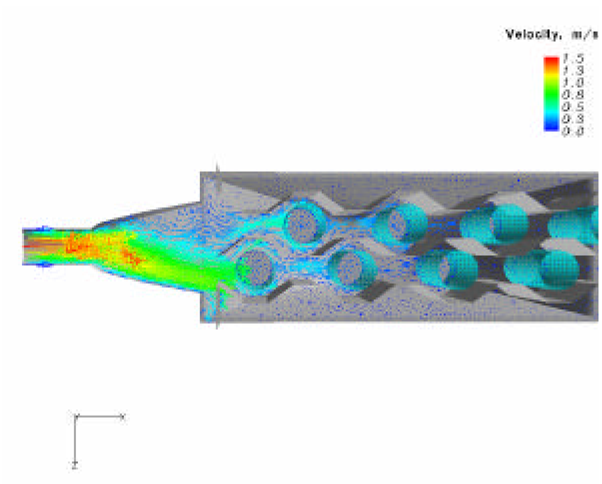
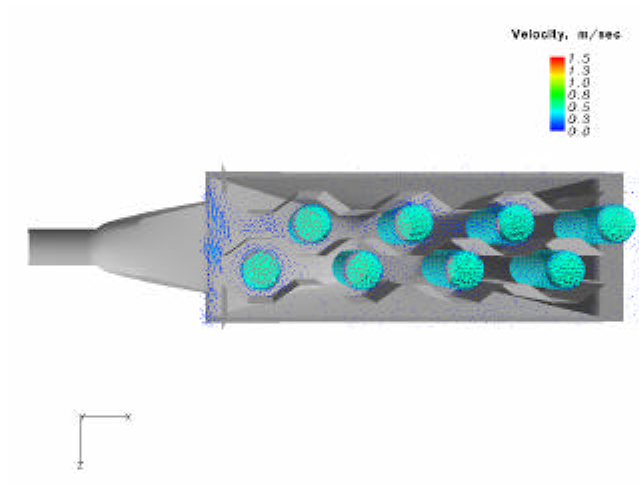
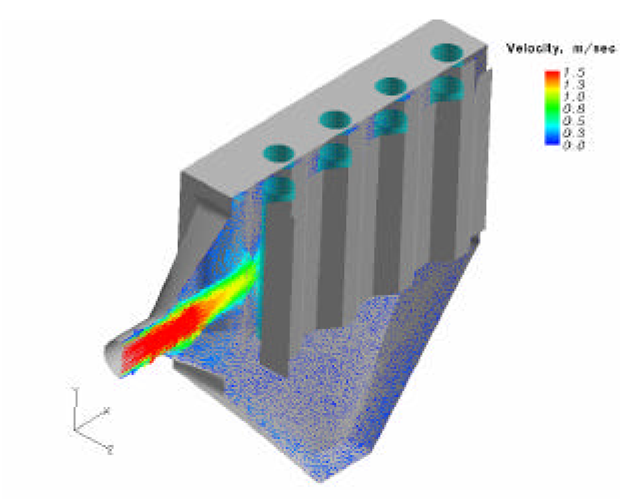


Figure 12. CFD Simulation. Bags Exit Gas Flow. Top View



The model included MSC inlet, filtration bags and internal electrodes. The model included MSC inlet, filtration bags and internal electrodes. The gas flow properties for CFD model were based on the data from Table 1. The simulation was based on ideal gas with air properties; two parameters ?e turbulence model was employed with smooth wall boundary condition on MSC™ wall and internal electrodes and barriers.

Figure 13. Gas Recirculation in the Hopper

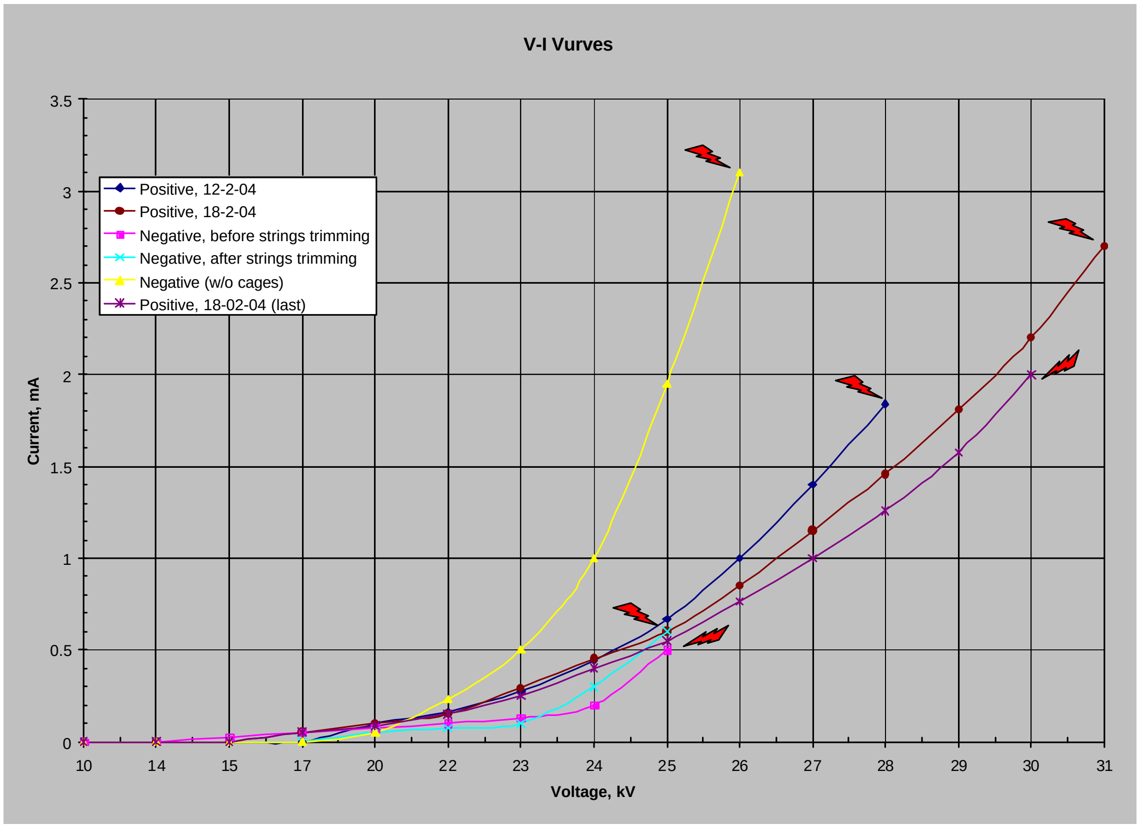


Approximately 150,000 unstructured-mesh cells were used for the current simulation. The results of the CFD simulations are presented on Figures 8 through Figure 11 in terms of gas flow distribution in different planes. One can see from the simulation results that gas is distributed relatively evenly among the bags due to high resistance of the bag cloth to the flow. A small gas recirculation zone is observed inside the hopper (Figure 12), but the values of the velocities there are small and probably will not cause any problem. Also, a recirculation zone is present where the gas entering MSC™ hits internal plate.

4.6 DEMONSTRATION MSC™ START-UP AND SHAKE-DOWN TESTS

The pilot MSC has been setup at the FERCo facility as shown in Figure 7. Prior to running the ash loading tests with the natural gas combustion products, a series of tests were run to characterize the voltage-current (V-I) response of the pilot-scale unit.

Figure 14. Demonstration MSC™ Electrical Clearances Evaluation



A high-voltage power supply with the ability to provide both positive and negative voltage was utilized to charge the corrugated plates. The goals of these shake-down tests were two-fold. The first was to evaluate the electrical clearances in the pilot-scale unit and to identify any plate/electrode/BFE alignment issues that would result in premature "back corona" or sparking. Once any alignment issues were identified and corrected, the V-I response of the unit was fully characterized.

Figure 15. View into Bottom of the Pilot MSC Unit

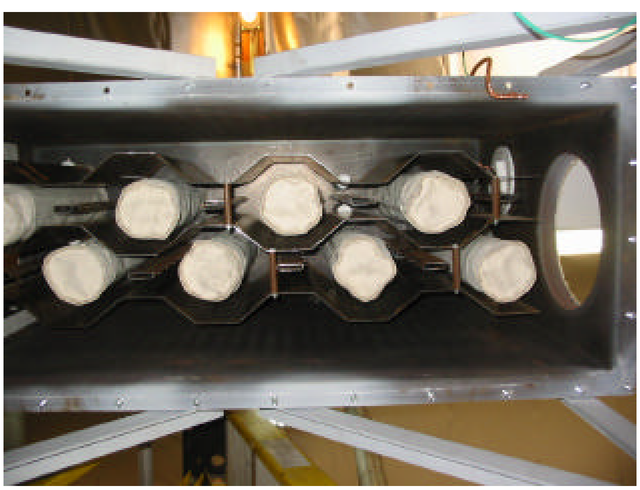


Figure 16. Sparking at the Top of the Electrode System

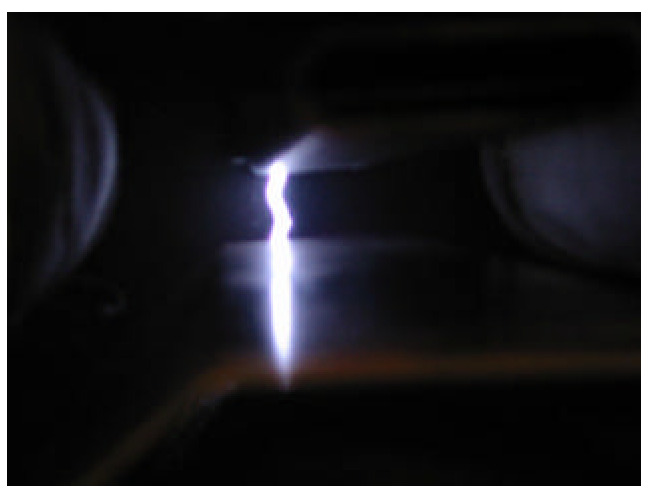


Figure 13 presents the results of the initial V-I characterization of the pilot MSC. The initial tests on 2/12/04 were run in the positive corona mode, and the maximum voltage attainable prior to the onset of sparking was 28 kV. These initial tests were run with the hopper, inlet and all inspection panels removed so that the areas of sparking could be identified and subsequently addressed. Figure 14 shows the view up into the bottom of the pilot unit where the plates, electrodes and BFEs can be clearly seen. Figure 15 illustrates the sparking phenomena occurring between an electrode and a plate at the voltage-limiting back corona condition. After optimizing the electrical clearances, the maximum achievable voltage increased to 30 to 31 kV as shown by the positive corona results for 2/18/04.

After optimizing the pilot unit in the positive corona mode, a series of tests were also run where a negative voltage was applied to the plates. As shown in Figure 13, sparking occurred at much lower voltages in the negative corona mode.

Overall, the shake-down tests indicated the V-I performance of the pilot MSC to be far better in the positive, rather than negative, corona mode.

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6.0 KEY WORDS

Electrostatic, Precipitator, Barrier Filter, Fabric Filter, Baghouse, Multi-Stage, Fine Particulate