

NEW MATERIALS AND PROCESSES FOR REGENERABLE COLLECTIVE PROTECTION AIR PURIFICATION SYSTEMS

Donald R. Cahela, L.Y. Chen, and Bruce J. Tatarchuk
Center for Microfibrous Materials Manufacturing, 304 Ross Hall, Auburn University, AL 36849

Michael W. Meffert
IntraMicron, Inc., 3595 Grandview Parkway, Suite 475, Birmingham, AL 35235

William A. Jacoby
Dept. of Chemical Engineering, W2016 EBE, University of Missouri, Columbia, MO 65211

Ronald B. Luster, John Nielsen, and C.H. Dunn
BE&K Engineering, 2000 International Park Drive, Birmingham, AL 35242

ABSTRACT

Recent advances in electrostatic precipitation/filtration, photocatalytic oxidation, and microfibrous materials technology have enabled the development of an improved ChemBio mitigation system for use in collective protection equipment applications. The new system combines high efficiency filtration of chemical and biological warfare agents and toxic industrial chemicals with low pressure drop and regenerability, reducing volume and power requirements as well as logistical and maintenance ownership costs. Electrostatic precipitation/filtration and photocatalytic oxidation of collected biomass provide a longer life, lower pressure drop alternative to traditional HEPA particulate filtration. Sintered metal microfiber-based media entraps micron diameter sorbent particles at high void volumes, increasing chemical warfare agent removal capacity while imposing minimal pressure drop.

INTRODUCTION

Collective protection equipment (CPE) has traditionally been reserved for protection of military facilities and sensitive government structures, such as the White House. Commercially, CPE has been used for security purposes in high value manufacturing processes, like semiconductor fabrication, and in hospital operating rooms, where mitigation costs are much lower than potential costs associated with infection. However, CPE product demand is increasing across a broader spectrum of applications in response to the widening recognition of the vulnerability faced by occupants in less secure governmental, military, and commercial buildings, transportation facilities (e.g., tunnels), and major event venues (e.g., stadiums).

CPE systems typically provide protection through overpressurization of the structure itself with the makeup air supply and simultaneous filtration of either the makeup air or the recycle air. Makeup air filtration protects occupants against a chemical or biological agent release occurring outside the structure (external release) while recycle air filtration provides protection against an internal release. In either case, airborne contaminants are removed through some filtration process before any humans or critical operations are exposed to the suspect air stream. Conventional CPE systems generally accomplish chemical and biological agent mitigation through two separate purification steps, particulate and biological warfare agent (BWA) removal with nonwoven HEPA (High Efficiency Particulate Air) filters, and adsorption or reaction of chemical warfare agents (CWA) in packed beds of sorbent and/or catalyst pellets.

This approach is well-developed, well-understood and proven, but overall performance is limited by various efficacy, cost and logistical issues related to fundamental inefficiencies in the technologies. Nonwoven HEPA filters impose a substantial pressure drop, which increases over time as captured particles plug and blind areas of the filter, particularly when biological matter retained in the filter fouls the media. These problems are minimized by replacement with fresh filter media at regular periodic intervals. Packed beds of sorbent pellets one to five millimeters in diameter suffer from high intraparticle mass transfer, requiring a large amount of continuous online inventory, which further increases pressure drop. Furthermore, once sorbent capacity is exhausted, replacing the bed contents to restore the protection envelope is a sizeable and time-consuming effort. Obviously, both traditional HEPA filtration and packed bed technologies incur a significant logistical tail to facilitate this constant media replacement. Better mitigation technologies and strategies are needed to extend protection broadly and continuously across the infrastructure of governmental and public structures in a cost-effective manner.

NEW MATERIALS AND PROCESSES

1. Microfibrous Materials Technology

Microfibrous media technology (MMT) developed at Auburn University provides new opportunities for improving CPE performance by eliminating inefficiencies associated with existing CPE technologies. The basic MMT element is a thin sheet of media consisting of a sinter-locked network of micron diameter metal fibers entrapping sorbent and catalyst powders at void volumes between 50% and 95%. Figure 1 below shows an SEM micrograph of microfibrous media composed of 55-85 μm activated carbon particles entrapped by a mixture of sintered 2, 4 and 8 μm diameter nickel fibers.

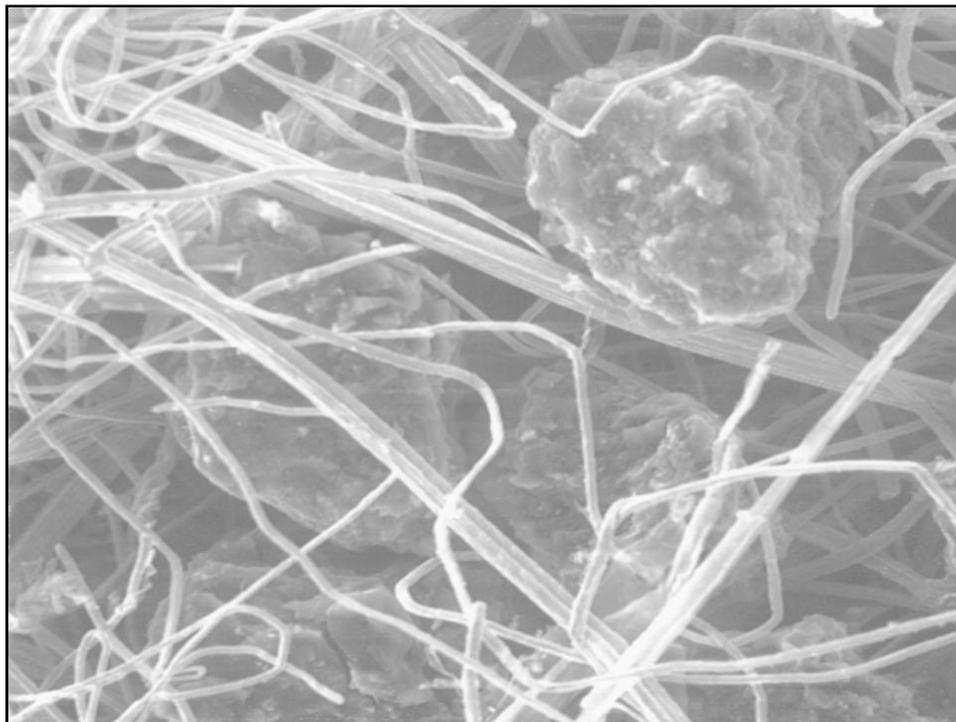


Figure 1. Micrograph of microfibrous media.

The use of sorbent and catalyst powders (*ca.* 100 μm diameter) virtually eliminates rate-limiting phenomena, namely intraparticle heat and mass transfer, commonly found in packed-bed systems while simultaneously improving contacting efficiency between the sorbent material and contaminants in the air

stream. The combination of better mass transport and higher contacting efficiency increases sorption capacity utilization by a factor of 3 to 4 or more compared to packed beds, which provides longer gas life with less active sorbent material. Because the microfibrous media is thin (0.5 to 5 mm thickness) and mostly void of solids, pressure drop through the filter is from about one-eighth to one-half that of a comparable packed bed of sorbent pellets. Thus, the power required by the HVAC fan or blower to pass air through the filter is greatly reduced, resulting in lower operational costs, and the size of the motor itself can be significantly reduced, cutting the initial capital outlay required for construction. Finally, microfibrous media can be customized by incorporating a range of sorbents and catalysts during manufacturing to address “cocktail” threats, providing a breadth of protection previously unavailable.

In the past, the high cost of micronic diameter metal fibers and problematic air-lay manufacturing techniques largely precluded their use in CPE applications. However, the microfibrous media technology is based upon reliable, proven, high-speed, roll-to-roll papermaking and sintering processes, substantially reducing production costs while improving product quality. Additionally, microfibrous media is thermally regenerable, permitting filters to be recycled/reused hundreds of times. Therefore, while microfibrous media filters might be somewhat more expensive initially, regeneration provides significant, recurring reductions in life-cycle maintenance, operational and environmental disposal costs.

2. Photocatalytic Oxidation Technology

Electrostatic precipitation (ESP) is a well-known technology in which particles in an airstream are ionized in an electric field and collected on a series of parallel plate electrodes in a flow-past arrangement. Compared to traditional HEPA filtration, ESP is somewhat less efficient, but with the benefit of having virtually no pressure drop. Electrostatic filtration (ESF) is an extension of ESP, except that ionized particles are captured by flowing through a relatively open, nonwoven filter element/electrode. ESF provides higher filtration efficiency than ESP, but at greater, although still minimal, pressure drop. Because ESP units impose almost no pressure drop, multiple units can be placed inline to provide filtration efficiency equivalent to conventional HEPA filters.

Photocatalytic oxidation (PCO) involves illuminating TiO_2 surfaces with ultraviolet radiation (<385 nm) to produce hydroxyl radicals and O_2^- ions, which are both powerful oxidation agents. Researchers at the University of Missouri have developed and demonstrated TiO_2 spray coating methods that enable PCO and ESP/ESF to be combined in a single filtration element. A TiO_2 -coated ESP unit is shown below in Figure 2.



Figure 2. TiO_2 -coated ESP unit.

By illuminating TiO_2 -coated ESP and ESF electrodes with ultraviolet radiation, collected particulate biomass, including spores, molds, and biological agents, is continuously oxidized and removed from the system. Units operated in this manner are therefore self-sterilizing and not subject to fouling. PCO-equipped ESP units also have a longer maintenance cycle since organic particulate matter is not allowed to build up and blind collection electrodes.

3. Combination of Microfibrous Material and ESP/PCO/ESF Technologies

Based upon previous discussion, the combination of microfibrous material and ESP/PCO/ESF technologies into a single CPE product as illustrated in Figure 3 has several logical and obvious benefits compared to the typical HEPA filter/packed bed approach. These benefits are

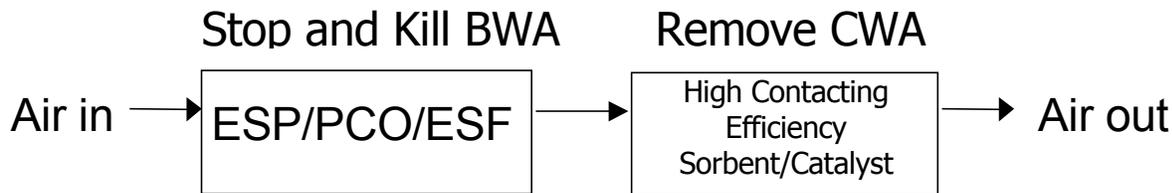


Figure 3. Combined ESP/ESF/PCO and microfibrinous media CPE application.

primarily related to operational, maintenance and life-cycle cost savings achieved by reducing the logistical tail associated with constant replacement of disposable filter media and lowering HVAC fan/blower power requirements by removing a substantial amount of pressure drop from the filter system.

The mitigation technology consists of front-end TiO₂-coated ESP and ESF units illuminated with UV bulbs to provide PCO at the collection electrodes (viz., an ultra low pressure drop HEPA filtration capability for biological agents) followed by high efficiency, low pressure drop microfibrinous sorbent media to remove CWAs, volatile organic compounds (VOCs), toxic industrial chemicals (TICs) and toxic industrial materials (TIMs).

TECHNOLOGY DEMONSTRATION

To demonstrate the feasibility and performance of the proposed CPE concept, individual modular components of the ESP/PCO/ESF and microfibrinous media technologies were fabricated and tested. Specifically, a 500 CFM capacity ESP/PCO/ESF unit and a 1000 CFM capacity chemical sorbent canister containing pleated microfibrinous media were constructed and tested, both separately and as a complete system. These units are shown below in Figure 4 assembled as a complete system for testing.

1. Pressure Drop

Because the ESP/PCO/ESF unit was designed for 500 CFM and the chemical sorbent canister for 1000 CFM, pressure drop measurements for each section are presented separately, and not as a complete system. Almost the entire pressure drop in the system was contributed by the chemical sorbent canister. The pressure drop through the canister at 1000 CFM was 1.8 inches of water while pressure drop through the ESP/PCO/ESF was very low, less than 0.1 inches of water, at its 500 CFM design capacity. A decrease in system pressure drop to 1.9 inches of water, compared to 6 to 10 inches of water pressure drop through a typical HEPA/packed bed CPE product, would save \$250 to \$500 per year in power costs, at 1000 CFM capacity and an electricity cost of \$0.04/kWh. At 10,000 CFM and \$0.40/kWh, a typical value for a remote location, these savings would amount to \$25,000 to \$50,000 annually.

2. Particle Collection Efficiency

Polystyrene latex (PSL) beads of various sizes were introduced into a HEPA-filtered airstream via atomization (TSI atomizer, model 3076) upstream of the ESP/PCO/PCF units. Collection efficiencies were calculated by comparing laser particle counter (MetOne Model A2400) measurements upstream and downstream of the ESP/PCO/ESF unit.



Figure 4. Modular filter system assembled for testing.

The collection efficiency of the ESP/PCO/ESF unit against a variety of challenges is shown in Figure 5. In comparison to defined HEPA efficiency, 99.97% collection efficiency of 0.3 μm particles, 99.96% collection was measured for 0.3 μm PSL beads, with somewhat higher efficiency for larger particles. This collection efficiency has been sustained during long-term testing for at least 30 days under a range of conditions, including variable humidity. These collection efficiency data do not include the mechanical filtration contribution of the microfibrinous media in the chemical sorbent canister. While testing has shown that microfibrinous media demonstrates an additional 75-80% collection of 0.3 μm PSL beads (>99.99% in series with ESP/ESF units), substantive mechanical filtration in the sorbent canister is not generally desirable, since plugging of the media particulate matter could shorten the life cycle.

3. Chemical Adsorption

Because of safety issues associated with DMMP and other simulants, n-hexane was tested at molar concentrations approximately equivalent to 1000 mg/m^3 of DMMP at 1000 CFM by sparging a portion of the feed air stream through a heated three liter capacity saturator. Hexane concentrations were measured using a photoionization detector (PID, Rae Systems) capable of detecting a 3.5 log reduction (0.1 ppm detection limit) in hexane concentration between the inlet and outlet airstreams.

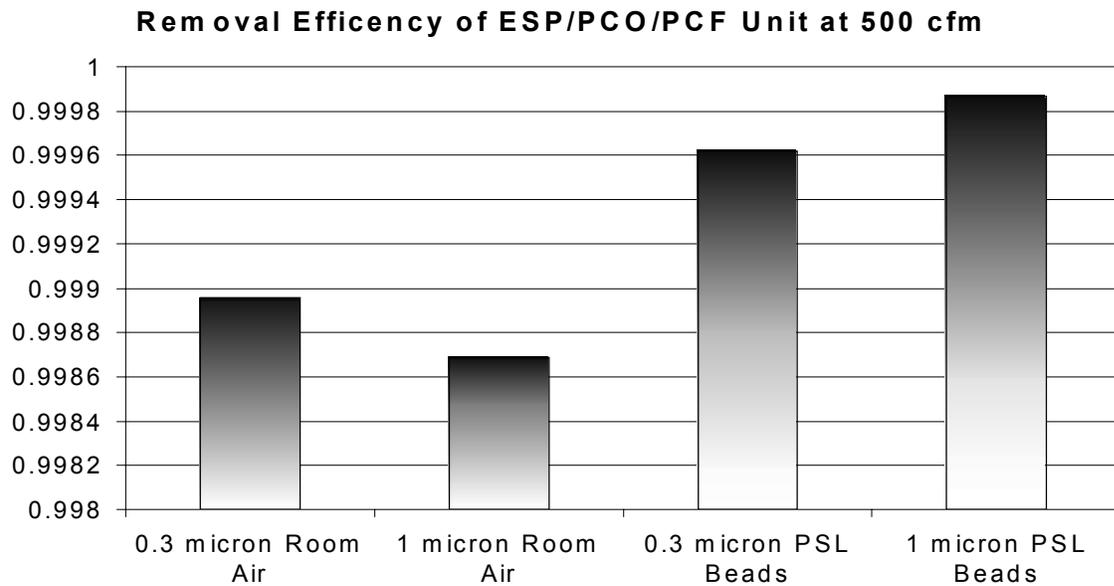


Figure 5. Filtration efficiency of ESP/PCO/ESF unit alone at 500 CFM.

Breakthrough curves for hexane challenges of 155 ppm at 1000 CFM and 210 ppm at 500 CFM are shown in Figure 6. Breakthrough times (@ 0.1 ppm detection limit) were 9.5 minutes and 18.5 minutes, respectively. The saturation capacity of Calgon BPL carbon, the activated carbon incorporated into the microfibrinous media, is 0.36 g DMMP/g carbon, four-fold higher than its saturation capacity for hexane, 0.09 g hexane/g carbon. Therefore, after correction for differences in challenge concentration and sorption capacity, the protection provided against hexane at 1000 CFM was equivalent to about 40 minutes of protection against a 1000 mg/m³ DMMP challenge.

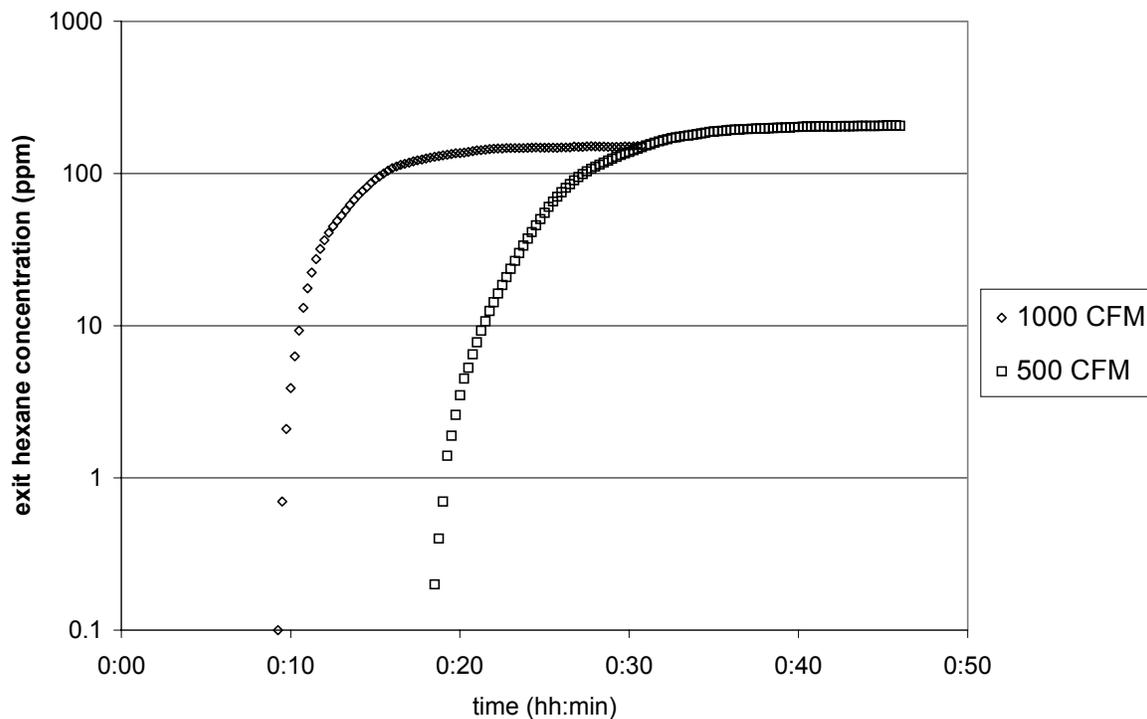


Figure 6. Breakthrough curves for hexane challenges.

4. Sorbent Regeneration

Thermal regeneration of sorbent in the microfibrinous media was accomplished by a programmed heating cycle while purging approximately 100 CFM through the canister with a small external blower. Temperature profiles in the canister were controlled by varying the outputs of separate heater elements. A typical hexane desorption curve during regeneration, overlaid with internal canister temperatures, is shown in Figure 7. The maximum hexane concentration measured in the purge air stream, 700 ppm, was much lower than the hexane LEL (11000 ppm). Notice the correlation between increasing canister temperatures and hexane concentrations. The hexane concentration reached about 700 ppm at 30 minutes when the canister temperature program ramp was held, and subsequently fell to 200 ppm at 60 minutes while adsorbed hexane was purged from the carbon media. At this time, the temperature ramp was resumed and more hexane was observed to desorb, until eventually all hexane was eliminated from the canister. Note that this resumption in hexane desorption corresponded almost exactly with the coolest temperature measurement in the canister (represented by TC4) exceeding the boiling point of hexane (140°F).

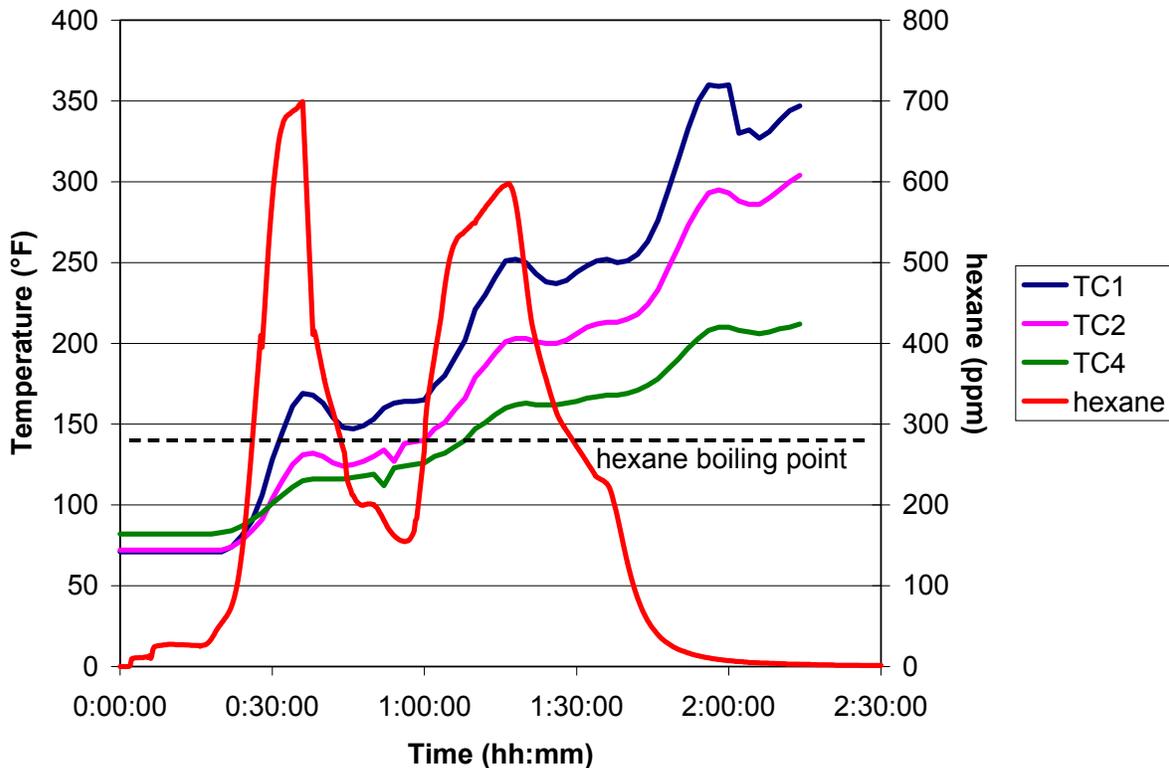


Figure 7. Hexane and temperature profiles during regeneration.

Several adsorption/regeneration cycles conducted over a six-week period demonstrated full sorbent regeneration was achievable and repeatable. Two hexane adsorption profiles, normalized to 180 ppm to simplify presentation, are shown in Figure 8. These profiles were recorded from two separate experiments performed more than one month apart with twelve intervening adsorption/regeneration cycles. Normalized breakthrough times were 8.0 and 9.0 minutes, with calculated sorbent saturation capacities of 0.076 and 0.081 g hexane/g carbon, respectively. This variation is consistent with repeatability observed during separate sorbent testing with hexane, DMMP and other challenges using virgin media.

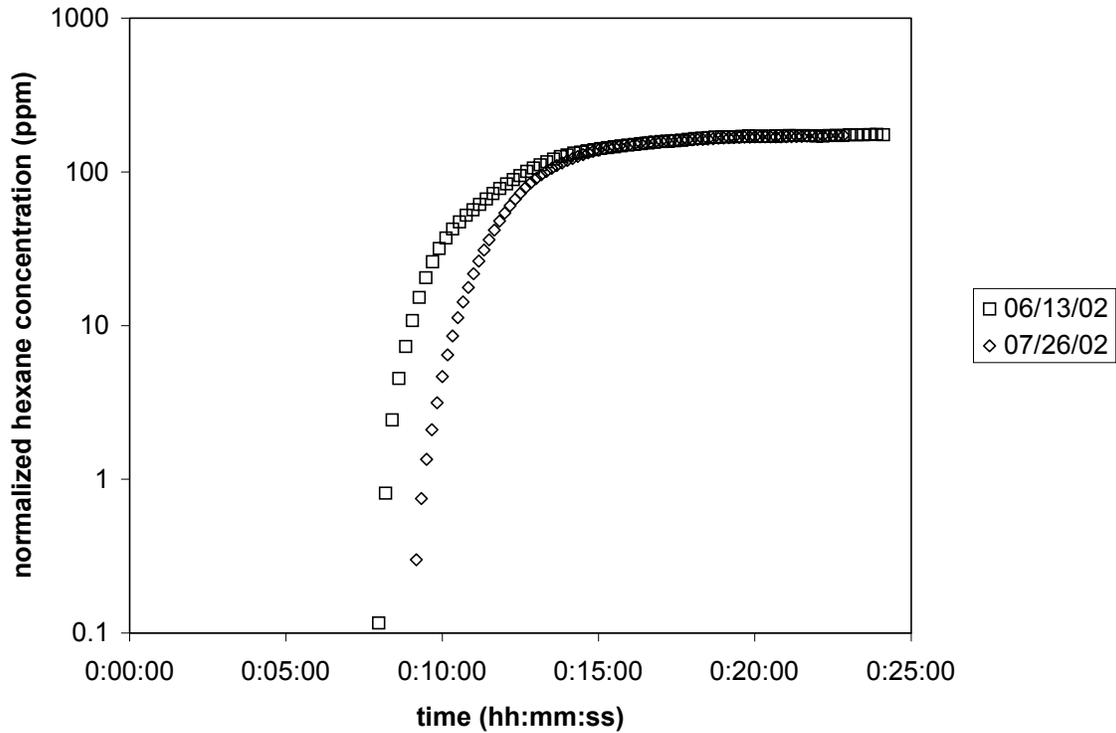
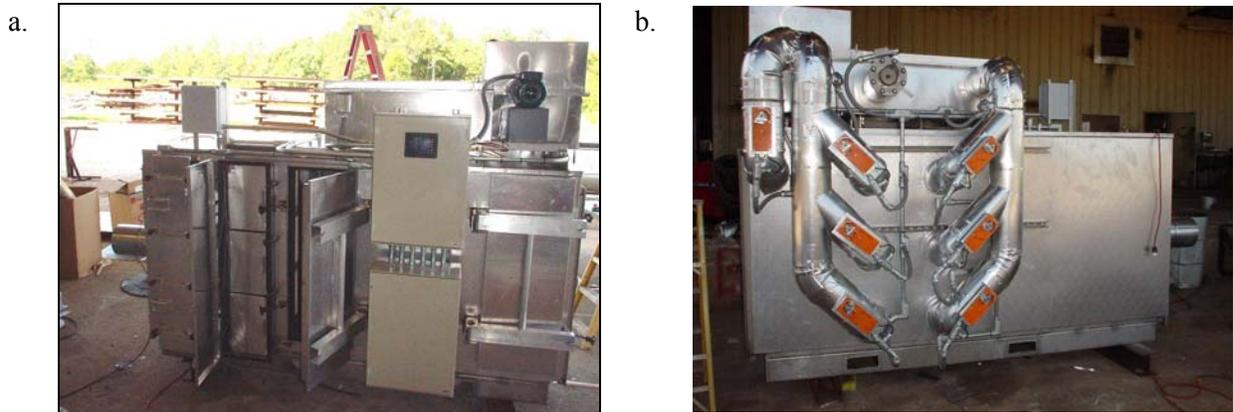


Figure 8. Demonstration of chemical sorbent canister regenerability.

5. Full Scale Unit

A fully integrated 3000 CFM filter system incorporating the ESP/PCO/ESF and regenerable microfibrinous media sorbent canister technologies discussed previously has been built, and performance equal to that presented above has been demonstrated. Pictures of this unit are shown in Figures 9a and 9b.



Figures 9. Pictures of 3000 CFM filter system.

As seen in the photos, this unit is equipped with heaters in external ductwork and a stronger purge blower to minimize intra-canister temperature differences during regeneration. Moving the heaters to external piping improved temperature distribution during regeneration, which reduced regeneration times and improved repeatability. The unit is weatherproof and designed to maintain NEMA 4X environment.

SUMMARY

The ESP/PCO/ESF microfibrinous sorbent media canister filter technology provides broad spectrum, comprehensive, continuous customizable filtration and mitigation for all identified ChemBio threats in air handling systems. This technology creates a new standard for CPE by raising the bar for both system performance and intangible benefits and attributes, including: HEPA filtration efficiency at a fraction of the normal pressure drop, elimination of blinding and plugging associated with traditional HEPA filters, continuous photocatalytic oxidation and detoxification of collected biomass, high efficiency, low pressure drop removal of chemical warfare agents and sorbent regenerability to reduce life cycle, logistical, maintenance, and operational costs.