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## CHEMICAL BIOLOGICAL CENTER

U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

ECBC-TR-870

### EXPLOSIVE DESTRUCTION SYSTEM'S DRUM FILTER PART 1. EXPERIMENTAL VALIDATION

Leonard C. Buettner  
John J. Mahle  
Robert W. Morrison

RESEARCH AND TECHNOLOGY DIRECTORATE

Edward Weller

**SAIC**

SCIENCE APPLICATIONS  
INTERNATIONAL CORPORATION  
Gunpowder, MD 21010-0068

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| 14. ABSTRACT<br><br>Product Manager, Nonstockpile Chemical Materiel Program Office, has developed a system to destroy nonstockpile munitions containing chemical warfare agents. This Explosive Destruction System (EDS) includes a filter to prevent vapors being released to the environment during draining of decontaminated agent from the destruction chamber. An assessment was required to ensure adequate toxic chemical filtration performance. Single-component testing of the filter with the decontaminant monoethanolamine (MEA) demonstrated sufficient capacity for three operations of EDS before MEA would exit the inlet noncombustible silica portion of the adsorbent bed and pose a fire risk to the downstream carbon bed. Single component breakthrough testing with the agent simulant dimethyl methylphosphonate (DMMP) indicated that the EDS could be used for destroying over 700 nerve or mustard filled munitions before the filter capacity for those agents would be exceeded. Six EDS filters tested to breakthrough with MEA decontaminated HD indicated no penetration of MEA (or any breakdown products) over the 6 h duration of the tests, equivalent to at least 40 operations of the EDS system. However, to prevent the risk of fire, the filter should not be used beyond the three operations over which the MEA is retained in the silica layer of the adsorbent bed. |             |                         |                               |                                                            |                                                                |
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## PREFACE

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# EXPLOSIVE DESTRUCTION SYSTEM'S DRUM FILTER

## PART I. EXPERIMENTAL VALIDATION

### 1. INTRODUCTION

The Product Manager (PM), Nonstockpile Chemical Materiel Program Office, requested the CB Filtration Team, U.S. Army Edgewood Chemical Biological Center (ECBC), to evaluate the performance of the filter design chosen to support the operations of the Explosive Destruction System (EDS). This report describes the results of two phases of the effort to assess the ability of the filter to remove toxic components that may be present during operation of the EDS. In the first phase, the filter was challenged with monoethanolamine (MEA) and dimethyl methylphosphonate (DMMP) vapors in air. MEA is a reactive constituent of the decontamination solution used in the EDS. DMMP is a chemical used to simulate nerve and mustard agent adsorption by activated carbon.

DMMP had been selected for this testing because of its ability to simulate nerve agent and mustard agent adsorption by activated carbon. However, DMMP is not a good simulant for HD reactivity. DMMP was expected to be less reactive than the nerve and mustard agents. Thus, using it to conduct the EDS testing would provide a safe-sided challenge to the EDS filter, while eliminating the safety risks associated with conducting agent testing. However, DMMP did react with the MEA, which necessitated a change to the experimental design of the test.

Because of the uncertainty in trying to simulate the complex composition of the challenge gas to the EDS filters, filters were ultimately challenged with decontaminated HD. By using an actual agent, the flow stream to the filter would be identical to that expected during the actual operation of the EDS when a HD round is destroyed. The HD had been decontaminated with a solution consisting of MEA and water in identical proportions to that planned in the actual operation of the EDS.

### 2. BACKGROUND

The PM Nonstockpile has developed the EDS to destroy explosively configured chemical warfare (CW) munitions. Specifically, the EDS uses shape charges to liberate the CW agent and destroy the burster followed by chemical treatment of the agent. The EDS uses a 6.5 ft<sup>3</sup> stainless steel pressure vessel to completely contain the blast, fragments, and shock wave from the detonation. The detonation of the round will result in a high-pressure within the vessel (60 lb/in.<sup>2</sup> gauge used for volumetric estimating purposes). After the round is opened, sufficient decontaminating solution (90% monoethanolamine or sodium hydroxide and water) will be pumped into the vessel to neutralize the agent released from the chemical round. The liquid and gases contained in the vessel will then be transferred to a collection drum. Displaced gases from the drum and the EDS overpressure will be exhausted through a filter to remove MEA vapors released from the decontaminating solution, as well as any remaining minute quantities of

unreacted agent vapors that might exist. Test data is needed to determine if the proposed filter design will adequately reduce the release of hazardous chemical vapors from the drum.

The filters, as submitted for testing, contained a cylindrical bed of ASZM-TEDA Carbon, 27 cm long and 10 cm in diameter. The carbon is contained in a 4 in. diameter Schedule 40 pipe of 316 stainless steel that is tapered at the inlet end. The filter includes a 316 stainless steel mist eliminator upstream of the carbon bed. Perforated plates support the bed at each end of the filter. Figure 1 shows side and outlet end views of the filter.



Figure 1. Side and Outlet End Views of EDS Filter.

### 3. FILTER REDESIGN

Two changes to the filter design ensued during the early stages of this testing effort. The first of these involved improvement to the way in which the adsorbent bed was retained in the filter housing. When the filters were received from their manufacturer, 5 to 20 g of carbon were noted to have escaped from the adsorbent beds of each of the filters. This adsorbent loss was attributed to the unsecured screening allowing carbon granules to exit the bed through the outlet end retaining plate. When the carbon bed is tightly packed, this screening was pressed against the retaining plate. However, when settling of the bed occurred during transportation of the filters, the screening no longer fit snugly and carbon granules exited the adsorbent bed at the outlet end of the filter. In addition, the perforation plate used for particle retention was found to be too coarse to retain the smallest particles of the 12x30 mesh particle size distribution of the ASZM-TEDA Carbon. Although the loss of 20 g of carbon adsorbent is not a significant part of the total amount of adsorbent in the bed (about 1.5 kg), the loss of adsorbent could adversely affect filter performance because of the risk of the adsorbent bed integrity being compromised. The problem was resolved by shipping the retaining plates to the filter manufacturer (Unisorb Corporation, South Houston, TX) for welding the screening to the plates. The screening, which was welded, was much finer than that of the original filter design. The modified plates were inserted into the filters and no further adsorbent particle by-pass problems were encountered.

The second change to the filter design involved the composition of the adsorbent bed. Initial MEA breakthrough testing\* of the filter filled with ASZM-TEDA Carbon resulted in a filter fire. This fire occurred after one of the filters had been challenged until MEA broke through the adsorbent bed of the filter. The challenge was then stopped for about 15 min. The airflow was then restarted in an attempt to verify the responsiveness of the breakthrough detector. At this point, flames erupted from the filter effluent. The airflow was then stopped. The carbon bed was flooded with nitrogen to deprive the fire of oxygen, resulting in the fire being quickly extinguished. The fire was attributed to heat generated by the reaction of adsorbed MEA, either with the ASZM-TEDA impregnation formulation or with the carbon surface. During the time that the flow was stopped following termination of the MEA challenge, heat built up in the bed without airflow to dissipate it. When the airflow was restarted, oxygen was then available to support combustion of the carbon adsorbent bed. This fire hazard has been reported for carbon filters with other vapor challenges, especially ketones.<sup>1,2</sup> These fires have been attributed to heat released during oxidation of the adsorbed chemical by chemisorbed oxygen on the carbon surface.

Because of this fire, the adsorbent fill of the filter was changed from the original composition of all ASZM-TEDA Carbon to a layered bed of one-third fill, by weight, of silica (W.R. Grace, Grade 408) at the inlet end followed by two-thirds fill of ASZM-TEDA Carbon. With this composition, preliminary estimates indicated that more than enough silica would be available to adsorb the MEA vapor vented from the EDS system during the destruction of an

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\* The term "breakthrough testing" refers to a laboratory procedure used to determine filter penetration time under a standard challenge condition (concentration, flow rate, relative humidity, etc.) to a predetermined effluent concentration.

agent-filled round. Further, because silica is noncombustible, the fire hazard caused by the MEA would be eliminated. The ASZM-TEDA Carbon layer was included because of its demonstrated performance in sorbing all chemical warfare agents. Although agent is not expected in the effluent from the EDS, it was considered prudent to include activated carbon in the filter fill, not only to address any unforeseen operational contingencies involving agent, but also because carbon will remove a wide variety of other organic materials.

#### 4. TESTING APPROACH

##### 4.1 Phase I.

The Phase I test plan consisted of nine breakthrough tests, consisting of MEA and DMMP challenges, to the filter containing only ASZM-TEDA Carbon as the adsorbent. MEA was chosen because it is the primary reagent used to decontaminate mustard agent, and DMMP was chosen because it is a recognized simulant for strongly physically adsorbed materials such as nerve agents and mustards. However, the test plan was changed to address the change in adsorbent bed composition, resulting from the inclusion of the silica layer because of the filter fire. The revised test plan consisted of the following breakthrough tests.

##### 4.1.1 MEA Breakthrough Tests.

MEA breakthrough tests were conducted on three filters filled with silica comprising one third of the bed, by weight, with the remaining two thirds being inert glass beads. This test will quantify the amount of MEA that can be filtered by the silica to ensure that sufficient capacity is available to prevent the MEA from entering the carbon layer. By keeping the MEA out of the carbon portion of the bed, the risk of fire will be eliminated.

##### 4.1.2 DMMP Breakthrough Tests.

DMMP breakthrough tests were conducted on three filters filled with the actual adsorbent bed composition (one-third silica, by weight, followed by two-thirds ASZM-TEDA Carbon) used in the filters. As noted above, DMMP is a recognized simulant for the adsorption of strongly physically adsorbed agent vapors (e.g., nerve agents and HD) on activated carbon. This test would quantify the amount of pure agent vapors, which could be removed by the EDS filter.

##### 4.1.3 Mixed MEA/DMMP Breakthrough Tests.

Mixed MEA/DMMP breakthrough tests were conducted on three additional filters filled with the modified (one-third silica and two-thirds ASZM-TEDA Carbon) adsorbent bed composition. These tests were to be conducted in air consisting of a mixture of 10% DMMP and 90% MEA/water mix (90% MEA and 10% water). The effluent was monitored for MEA and DMMP.

The Phase I filters were challenged using the parameters described in Section 5. The filter breakthrough was determined as the time when the effluent concentration of the challenge chemical rises to the value stated below Section 5.2.

#### 4.2 Phase II.

A total of six EDS filters were tested with vaporized challenge solution resulting from the decontamination of HD with MEA and water. The solution was prepared by mixing 10% water with 90% MEA. Then nine parts of this solution were mixed with one part HD. The solution was monitored for residual HD using a GC/MS analysis with a minimum detectable limit of 13 parts per billion, no HD was detected. The six filters tested were filled with layers of fire-resistant silica (about 0.5 kg) and ASZM-TEDA Carbon (about 1.0 kg) as designed during Phase I.

The Phase II filters were challenged using the parameters described in Section 5. The filter breakthrough was determined as the time when the effluent concentration of the challenge chemical rises to the value stated below in Section 5.4.

### 5. PARAMETERS OF THE TESTS

#### 5.1 Challenge Concentration of MEA.

Because a large amount of MEA liquid will be present in the drum into which the chamber is vented, the air leaving the drum would be expected to be nearly saturated with MEA vapor. Thus, the MEA challenge used to conduct the breakthrough tests was set at a concentration as close to saturation as can be achieved, while maintaining a stable concentration. Initially the goal was to perform the MEA tests with a challenge at 80% of saturation. However, this concentration was found to be unachievable especially when water vapor was also present. To ensure a stable MEA feed concentration, the tests were conducted at 25% of saturation as a consequence of Raoult's law. Although substantially below the goal, this lower concentration in no way diminished the ability of the test to quantify filtration performance for MEA. Being a relatively low vapor pressure chemical, MEA is strongly adsorbed by microporous adsorbents, such as activated carbon and fine pore silica. Thus, the loading of MEA on the carbon at 25% of saturation would not be expected to differ greatly from that at 80% of saturation. This insensitivity of adsorbed phase loading with vapor phase concentration is typical of the absorption equilibrium of cyclohexane on silica reported by Sircar and Myers.<sup>3</sup> The cyclohexane adsorption isotherm shows nearly the same adsorbed phase loading from saturation down to 25% of saturation.

#### 5.2 Challenge Concentration of DMMP.

Although any agent concentration will be extremely small, the DMMP challenge concentration was set at approximately 12% of saturation to reduce the time needed to achieve DMMP breakthrough to a reasonably short duration. Because DMMP and the nerve/HD agents

that it simulates are strongly adsorbed by microporous adsorbents, loading on the adsorbent is relatively insensitive to challenge concentration when dealing with higher concentration levels.<sup>4</sup>

### 5.3 Challenge of Decontaminated HD.

The vapor challenge during the Phase II testing of decontaminated HD, using the EDS filter, was about 25% of the saturated vapor concentration of MEA. The concentration was substantially below saturation levels to eliminate the possibility of condensation, which would result in an inconsistent challenge.

### 5.4 DMMP and MEA Breakpoint Concentration.

The times at which the test chemicals DMMP and MEA penetrate the filter were determined for an effluent concentration of  $0.0001 \text{ mg/m}^3$  for DMMP and  $0.05 \text{ mg/m}^3$  for MEA. The goal was to measure MEA breakthrough at  $0.0001$  or  $0.003 \text{ mg/m}^3$  (which are the exposure limits for GB and HD, respectively), but sufficient GC detector sensitivity could not be obtained. However, from an industrial hygiene standpoint, it is still valuable to know the capacity of the EDS filter for MEA because MEA is the most prevalent chemical in use during EDS operations. Because the threshold limit value time weighted average (TLV-TWA) for MEA is  $7.5 \text{ mg/m}^3$ , the  $0.05 \text{ mg/m}^3$  breakpoint concentration is more than adequate for this compound.<sup>5</sup>

### 5.5 HD/MEA Breakpoint Concentration.

HD was monitored at a concentration lower limit of  $0.001 \text{ mg/m}^3$ , which is well below its exposure limit of  $0.003 \text{ mg/m}^3$ . MEA was monitored down to a  $0.05 \text{ mg/m}^3$  concentration stated above for the Phase I testing.

### 5.6 Flow Rate.

Based on preliminary information on the operation of the EDS, the maximum flow rate of the gases exiting the vessel is 53 cubic feet per minute (CFM), which decreases by 50% within 30 s. However, based upon estimates of the back-pressure within the waste drum at this flow (caused by the flow restriction of the EDS filter), the need to restrict the gas flow out of the EDS (or provide additional expansion volume prior to the filter) was recognized. Based upon discussions with Dr. Tim Shepodd of Sandia National Laboratories, a 14 CFM maximum flow during venting of the EDS was assumed for these filter evaluations. This 14 CFM flow is equivalent to an airflow velocity through the carbon bed of the filter of 158 ft/min (80.4 cm/s).

### 5.7 Temperature.

Testing was performed at  $50^\circ\text{C}$ , which is the expected maximum temperature for the filter. This maximum value represents the worst case temperature condition because adsorption capacity decreases as temperature increases for a given gas phase concentration.

## 6. TEST EQUIPMENT

A test apparatus was specifically designed and fabricated to conduct this testing. The apparatus is shown in the photographs included as Figures 2 and 3. Figure 2 shows the plumbing of the test system, and Figure 3 shows the analytical section.

The liquid challenge chemical (90% MEA, DMMP, or decontaminated HD solution) was fed from an enclosed bottle (1 on Figure 2) sitting on a weighing balance (2). The liquid chemical is withdrawn at a constant rate from the bottle with a precision metering pump. This metering pump (3) is located beneath the balance in Figure 2. The chemical is fed to a nozzle inside at the top of the vaporization column (4) located at the center of Figure 2. Air, warmed by a preheater (5) to 50 °C, is fed upward at 14 CFM through the vaporization column. The air flow rate is maintained and measured by a Tylan mass flow controller (6). The column is wrapped with heating tape to aid in the vaporization process. The chemical vapor/air mixture passes out of the top of the evaporation column and prior to the start of the test is vented into a condensate collection vessel (7) located immediately to the right of the vaporization column, then through a vent filter (8) for collection. When the test is started, the challenge chemical is fed to the top of the test filter located in an insulated enclosure (9), which can be seen immediately to the right of the receiver. The outside of the filter is temperature controlled by water at 50 °C flowing through copper tubing that coils around the filter. A small flow (20 cm<sup>3</sup>/min) of the challenge concentration is pulled from the top of the vaporization column for monitoring by the GC (10) seen in Figure 3. The GC is a Hewlett-Packard Model 5890 equipped with a flame ionization detector for MEA and DMMP challenge concentration monitoring, as well as a flame photometric detector for DMMP breakthrough analysis. In monitoring the challenge concentration, the GC was used essentially to verify the stability of the feed concentration. The feed concentration for each of the tests was quantified from the mass of chemical fed in the 14 CFM airflow passing into the filters under test.

The effluent concentration is monitored using the same GC described above. However, because extremely low concentrations need to be measured, the chemical vapors in the effluent sample stream were concentrated using a modified Dynatherm ACEM900 vapor concentrator (11) seen on the top left side of the GC in Figure 3. The Dynatherm collects the vapor to be analyzed from the sample stream for a period of time, dictated by the concentration level sought in the analysis and the frequency at which analyses are desired. The sample collection tube is then heated, transferred to a focusing trap, and injected into a GC column for separation of chemical components and subsequent quantification by detector response.

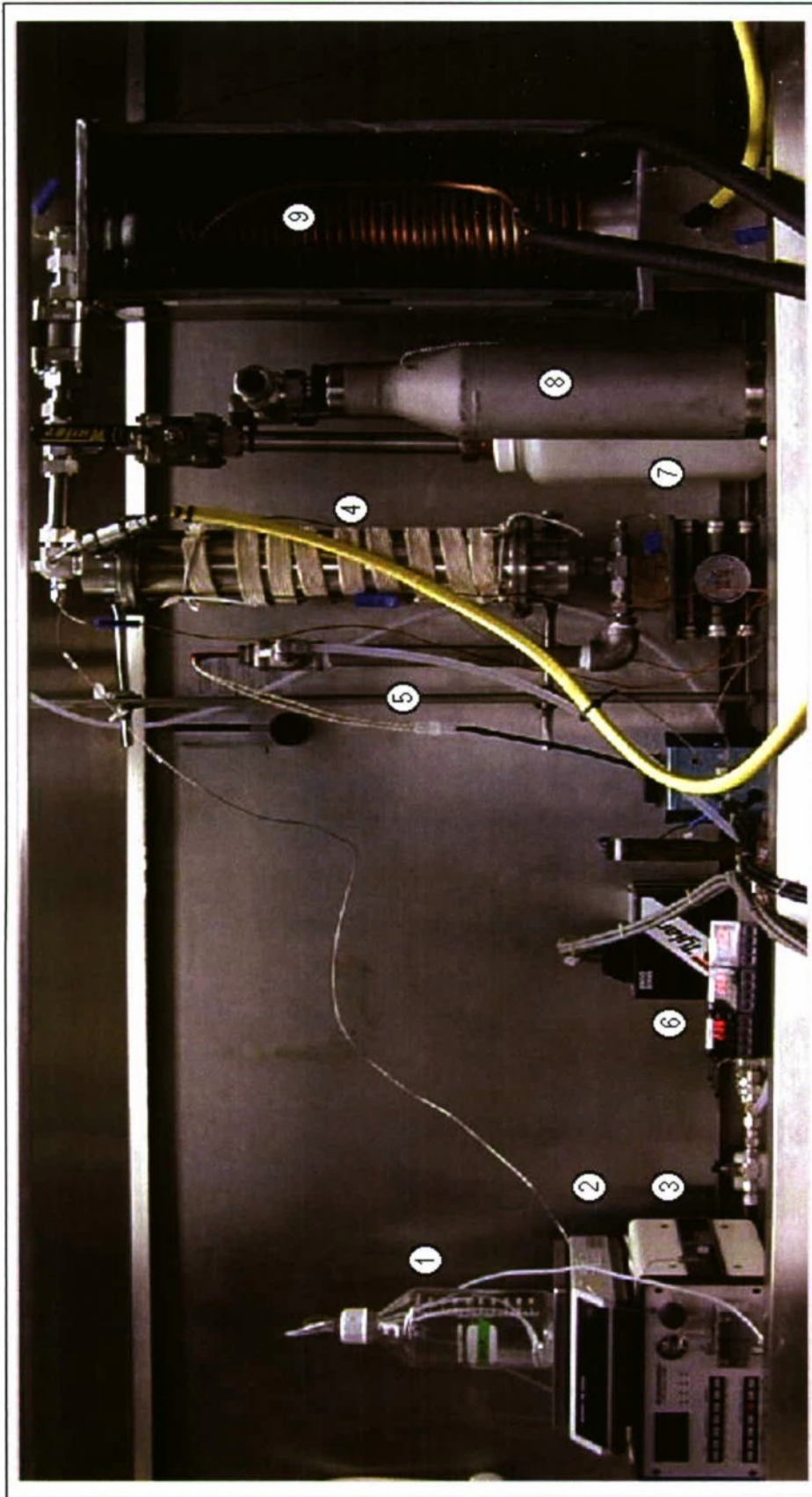


Figure 2. Test Apparatus for EDS Filter Assessment.

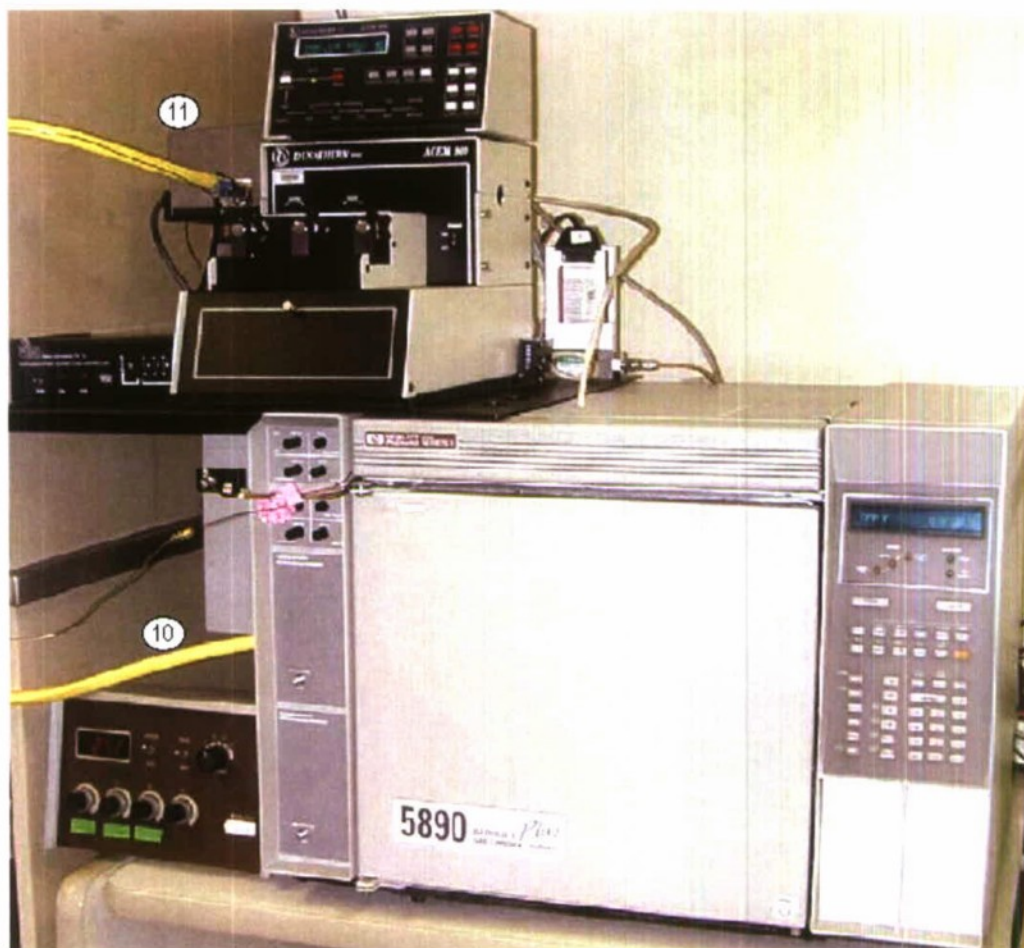


Figure 3. Analytical Instrumentation Associated with EDS Filter Test Apparatus.

## 7. RESULTS

### 7.1 Carbon-Only Tests: MEA Challenge to Filters Filled with ASZM-TEDA Carbon.

Two tests were conducted challenging ASZM-TEDA Carbon filled filters with MEA at a concentration of  $4,870 \text{ mg/m}^3$  under dry conditions. In the first test MEA, breakthrough was detected 3 h and 10 min after initiation of the feed stream concentration. However, the second test resulted in a significantly shorter time of 2 h and 32 min. The challenge flow was stopped and checks were made of the test equipment and test parameters to insure that everything was in order. The flow was restarted and flames were observed exiting the filter. A likely cause of this fire is described above in the filter redesign section of this report. The shorter breakthrough time of the second filter test was likely the result of heating resulting from the beginnings of oxidation of MEA.

The first test indicated that the filter when filled with ASZM-TEDA Carbon has a capacity of 366 g of MEA. Based on an effective volume of the EDS chamber of  $6.0 \text{ ft}^3$ , an

initial pressure of 60 psig and the air leaving the collection drum being saturated with MEA, the expected amount of MEA vapor, would pass into the filter per use of the EDS system is 7.0 g. This calculation (see Appendix) neglects the volume taken up in the chamber by the decontaminated agent solution. Thus, the filter, when filled with ASZM-TEDA Carbon alone, would have sufficient capacity for use in over 50 operations of the EDS. However, the fire necessitated the change in the bed composition described above.

## 7.2 MEA Challenge to a Bed of One-third Silica (No ASZM-TEDA Carbon).

The MEA challenge concentration for these tests was established by feeding a 90% by weight MEA, 10% water solution at 1.08 g/min into 14 CFM of dry air. At this flow rate, the challenge concentration of MEA to the three filters tested was  $2,450 \text{ mg/m}^3$ . This concentration represents about 25% of the saturation concentration for MEA. The three tests of filters filled with one-third of silica followed by inert glass beads resulted in breakthrough occurring after 22, 22, and 24 min. As described above, the use of the Dynatherm to measure the low concentration levels resulted in the ability to determine breakthrough within 20 min windows of time due to the sample cycling time. (The breakthrough times differ slightly from 20 min because of a small delay in initiating sampling at the start of the test.) Thus, the actual breakthroughs occurred sometime between the stated values and 20 min after the values. The mean of these three minimum breakthrough times is 23 min, which equates to a mass of MEA adsorbed of 22 g/test. Because the maximum mass of MEA vapor expected to challenge the filter in actual use during destruction of one round is 7.0 g, the filter will provide enough capacity to be used for three operations of the EDS before the MEA would enter the carbon portion of the filter bed.

## 7.3 DMMP Challenge to a Bed of One-third Silica and Two-thirds ASZM-TEDA Carbon.

The DMMP challenge for these tests was established by feeding 1.21 g/min of DMMP into the 14 CFM of dry air resulting in a challenge concentration of  $3050 \text{ mg/m}^3$ . The three tests of filters resulted in breakthrough times of 397, 360, and 390 min. The average breakthrough time of these three tests is 382 min. Thus, the filter capacity to breakthrough at this feed concentration is 462 g of DMMP. Figure 4 shows the challenge concentration and effluent concentration measurements for the 390 min breakthrough time experiment.

The most volatile of the physically adsorbed agents is GB. Although unrealistically high, assume for example that the GB vapor concentration were 1% of saturation (GB saturation concentration at  $50^\circ\text{C}$  is  $90,400 \text{ mg/m}^3$ ). That condition would result in a challenge concentration to the filter of  $904 \text{ mg/m}^3$ . Because the bleed down gas volume of the EDS chamber from 60 psig is  $24 \text{ ft}^3$  ( $0.68 \text{ m}^3$ ), the total mass of GB that would be fed to the filter during one operation of the EDS is about 0.61 g. Thus, the filter would have sufficient agent capacity for over 700 GB operations.

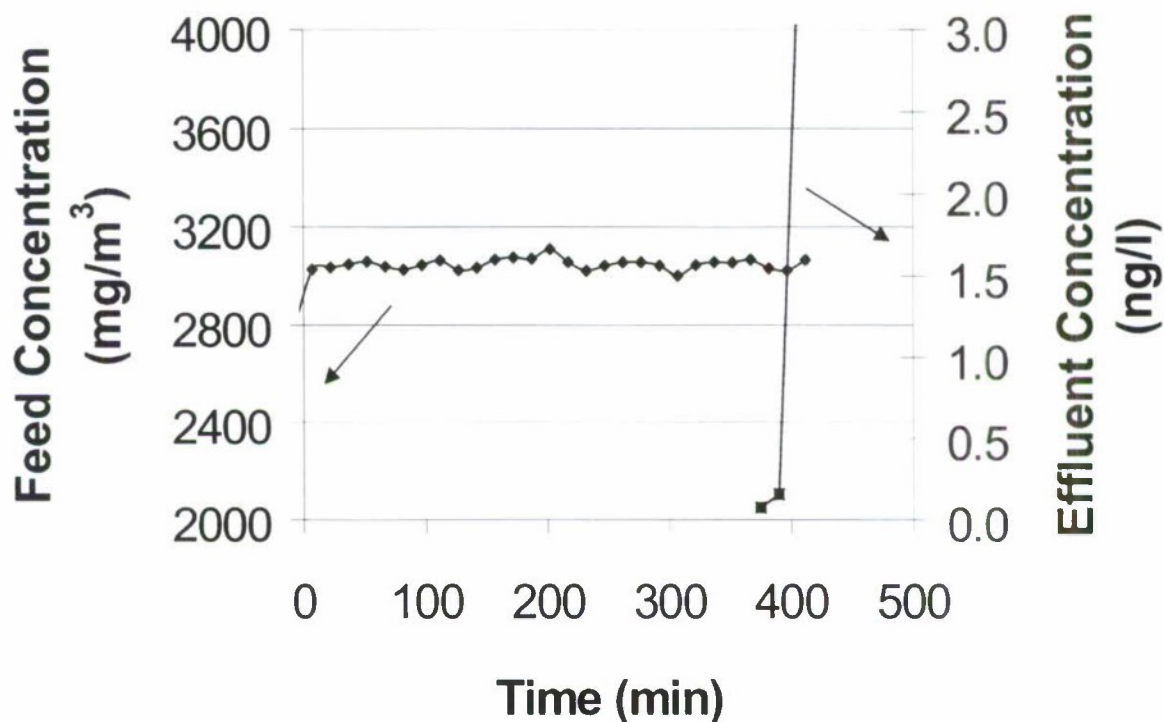


Figure 4. DMMP Challenge of Silica Gel/ASZM-TEDA.

7.4 DMMP/MEA/Water Challenge to a One-third Bed of Silica Followed by Two-thirds Bed of ASZM-TEDA Carbon.

These tests could not be completed because of an apparent chemical reaction of DMMP with MEA. A test was conducted for 8 h during which time DMMP was not detected in either the feed or the effluent. MEA was detected in the feed but not the effluent. The GC indicated the presence of numerous reaction products in the effluent. Studies have supported the use of DMMP as an acceptable simulant for physical adsorption on activated carbon, but its suitability to simulate reactive processes has not been established. Thus, this portion of the test plan was discontinued because the filtration results would not be expected to be indicative of an actual decontaminated agent challenge. Instead breakthrough testing was performed with a solution of HD decontaminated with MEA/water. This was considered to be a more realistic challenge mixture.

7.5 HD/MEA/Water Challenge to a One-third Bed of Silica Followed by Two-thirds Bed of ASZM-TEDA Carbon.

Six EDS filters containing silica layered with activated carbon were challenged with the vaporized HD/MEA/water at the above stated test parameters. No HD was detected in the effluent from any of the tests. Each of the tests was terminated at the point that the

concentration of MEA in the effluent overwhelmed the GC detector. The MEA breakthrough times at the TLV-TWA concentration of  $0.05 \text{ mg/m}^3$  for the six filters were 289, 229, 389, 288, 289, and 328 min. The average breakthrough time of these three tests is 302 min. These times represent a filter capacity for over 40 operations of the EDS. However, to eliminate the risk of a filter fire, the MEA adsorption wave must not leave the silica adsorbent layer. Thus, the three operations of the EDS filter between filter change-out, rationalized in Section 7.2 above, are appropriate.

## 8. CONCLUSIONS

After the cooling airflow was cycled off for 15 min—then back on, ASZM-TEDA Carbon spontaneously ignited when saturated with >19 mass percent of MEA. As a result of this work, the effected changes to the filter design resulted in improvement in maintaining adsorbent bed integrity and significantly reduced the risk of a filter fire.

The mean monoethanolamine (MEA) capacity (at 14 CFM flow rate) of the silica gel portion of the EDS filter is 22 g prior to an effluent concentration of  $0.05 \text{ mg/m}^3$ . Based upon a maximum of 7.0 g of MEA vapor generated per munition processed in the Explosive Destruction System (EDS), the EDS filter could be used for 3 munitions without loading MEA on the carbon portion of the filter bed.

The mean dimethyl methylphosphonate (DMMP) capacity (at 14 CFM flow rate) of the redesigned EDS filter is 462 g. This equates to 700 EDS operations involving GB or HD.

Filter testing with a mixture of DMMP and MEA was unsuccessful in evaluating filter “life.” This was due to an apparent chemical reaction between the DMMP and MEA.

Testing with the decontaminated HD indicated that the revised filter design would perform adequately in field operations of the EDS system. Based on flammability issues associated with MEA, filter change out should occur after every three operations of the EDS.

The mean DMMP capacity (at 14 CFM flow rate) of the entire EDS filter bed (silica plus ASZM-TEDA Carbon) is 462 g, prior to an effluent concentration of  $0.0001 \text{ mg/m}^3$ . Based upon the volume of gas produced for a single munition being processed in the EDS, this capacity would be equivalent to over 700 EDS operations involving the nerve agent GB.

A mixture of DMMP and MEA could not be used to simulate an EDS waste stream because of the reactivity between the two chemicals.

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## APPENDIX

### CALCULATION OF MASS OF MEA VENTED INTO THE FILTER DURING EACH OPERATION OF THE EDS

#### 1. Assumptions.

- a. Volume occupied by the decontaminating solution is neglected based on the variability of this factor. (This assumption adds to the conservativeness of the analysis.)
- b. The air entering the EDS filter is saturated with MEA.
- c. The air entering the EDS filter is at standard atmospheric pressure of 14.7 lb/in.<sup>2</sup>.

#### 2. Calculation.

##### a. MEA Saturation Concentration

The vapor pressure of MEA at 50 °C is estimated as 3.35 mm Hg. This value was obtained from a Clausius-Clapeyron interpolation of MEA vapor pressure data found in the Merck Index (10th Ed, 1983) and the Handbook of Chemistry and Physics (65th Edition, 1984). This vapor pressure is equivalent to a volatility of 10,150 mg/m<sup>3</sup>, calculated as follows:

$$\text{Sat. Conc.} = \frac{\text{vapor pressure} \times \text{molecular weight}}{\text{gas constant, R} \times \text{temperature}}$$

$$\text{Sat. Conc.} = \frac{3.35 \text{ mm Hg} \times 61.08 \text{ g/g mol}}{62.4 \text{ mm Hg} - \text{L/g-mol K} \times 323 \text{ K}}$$

$$\text{Sat. Conc.} = 0.01015 \text{ g/L} = 10,150 \text{ mg/m}^3$$

##### b. Volume of Gas Filtered.

$$\text{Effective volume of the EDS chamber} = 6 \text{ ft}^3 \text{ (6.5 ft}^3 \text{ vessel} - \text{approximately 0.5 ft}^3 \text{ occupied by munition remnants)}$$

$$\text{EDS chamber pressure} = 60 \text{ psig}$$

$$\begin{aligned} \text{Volume of gas at 14.7 psi released from EDS chamber} &= 6 \text{ ft}^3 \times 60 \text{ psi}/14.7 \text{ psi} \\ &= 24.5 \text{ ft}^3 \\ &= 0.69 \text{ m}^3 \end{aligned}$$

c. Mass of MEA Removed.

$$\begin{aligned}\text{Mass of MEA removed} &= \text{MEA concentration} \times \text{Volume of gas filtered} \\ &= 10.15 \text{ g/m}^3 \times 0.69 \text{ m}^3 \\ &= 7.0 \text{ g of MEA per EDS operation}\end{aligned}$$