Carbon Tetrachloride Attenuation in the WIPP Underground Ventilation Air Using a Granulated Activated Carbon (GAC) Volatile Organic Compound (VOC) Removal System - 11374

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ABSTRACT

Chemical constituents of some of the mixed waste packages received for disposal at the Waste Isolation Pilot Plant (WIPP) include volatile organic compounds (VOCs), including carbon tetrachloride (CCl_4). An increase in CCl_4 levels in the WIPP underground exhaust air was observed in 2009 and 2010 encroaching upon the state-issued Hazardous Waste Facility Permit action level. A temporary capture depletion system using granulated activated carbon (GAC) filtration was installed on an isolated space (plenum) created by installing a second bulkhead in one of the two drifts to underground disposal Panel 4, one source of CCl_4. The system test data, based upon four GAC filter sampling cycles from February 12, 2010 through March 30, 2010, indicate that the removal system was effective in reducing the concentration of CCl_4 in the air being circulated in the plenum. Initial reductions of about 90 percent in CCl_4 air concentrations were noted with a new filter in place, averaging an estimated 27 percent removal efficiency over the life of the filter. The test system removal rate under the observed conditions was a small percentage of the overall mine CCl_4 emissions, but demonstrated proof-of-principle that this VOC removal method was effective in VOC mitigation specific to CCl_4 under the conditions of the WIPP facility disposal system.

INTRODUCTION

VOC concentrations of CCl_4 in the WIPP mine ventilation exhaust air steadily increased beginning in July of 2009; additionally, the rate of increase appeared to be accelerating over time. To reduce the release of CCl_4 from filled Panel 4 into the ventilation air stream, installation of a GAC filtered recirculation system (FRS) was completed in the panel exhaust drift in February 2010. (See Fig. 1.) A trial evaluation was initiated using an isolated space created by installing a new bulkhead in front of an existing bulkhead at the exhaust side of filled Panel 4. The air mixture in this plenum between the two bulkheads was circulated through the GAC system to remove VOCs and then returned to the plenum. (See Fig. 2.) A formal approved test plan was used to evaluate the effectiveness of the GAC system.

The purpose of the test plan was to clearly define the operating parameters (e.g., sustainable airflow rates, VOC removal fraction, and filter change-out cycle) of the filtration system, and to determine the effectiveness of the GAC FRS in reducing CCl_4 emissions from Panel 4 [1]. The test design objective was to empirically determine the effectiveness of the GAC FRS as a means of reducing CCl_4 in the mine ventilation exhaust. A decrease in CCl_4 concentration in the mine ventilation exhaust was anticipated if the FRS performed as planned.

EQUIPMENT AND COMPONENT DESCRIPTIONS

The test equipment consisted of an Adam Equipment 300kg series CPWplus L® platform scale (Adam Equipment Co. Ltd, Milton Keynes, UK), for mass measurement, 6-liter passivated SUMMA-type canisters, with a passive air sampler assembly to collect a flow-controlled grab sample (used for routine sub-atmospheric VOC air sampling), anemometers and differential pressure gages as needed for airflow determination, and timekeeping devices (chronometers) for rate calculation.

The air treatment system was based on the AirRhino 2000® air filtration unit (Electrocorp Air Filtration Systems, Cotati, CA) set to run at a nominal 14.2 m^3/minute, or 0.236 m^3/sec (500 actual cubic feet/minute [ACFM]) filter flow rate. A thin particulate pre-filter was followed by a carbon filter cartridge containing about 38 kg (84 lbs) of granular activated carbon as the filter medium. The system removed air from a lower corner of a 45 m^3 (1,600 ft^3) plenum, formed by two

bulkheads, and returned the filtered air to the opposite upper corner through 30 cm (12 inch) diameter flexible metal ducting. Sample ports on the inlet and exhaust duct provided a means for *in-situ* sampling. (See Fig. 2.)

Filter mass loading was determined by subtracting the GAC filter unit tare (start) mass from the subsequent mass measurements and recording the readout differential in kg. The tare mass of the filter unit was determined at the start of the test, and the current mass (including filter gain) was periodically recorded on log sheets by operations staff, then forwarded electronically and documented on a consolidated data sheet. Airflow information provided by pre-installation engineering tests included manufacturer-provided fan performance ranges, differential pressure indicators, and preoperational flow measurements. *In-situ* calibrated airflow instrumentation measurements were not available for this system, so the airflow determinations were considered to be estimates. Airflow measurements (during initial testing) were calculated and documented on the data sheet as estimated flow rates. Differential pressure measurement readings across the filter taken during the course of operation were consistent with those recorded at the nominal 0.236 m^3/sec (500 ACFM) calculated airflow documented during initial testing.

Photoionization detector (PID) measurements of CCl_4 concentrations were conducted by WIPP Industrial Hygiene staff on the system inlet and exhaust duct, and plenum using a MiniRAE 3000[®] handheld PID instrument (RAE Systems, San Jose, CA). These measurements were taken initially for the purpose of worker safety monitoring, but played an increasing role in determining system operating status in real time. Logged CCl_4 concentration changes during startup of filters #1 and #3 provided an empirical basis for describing the effects of filtration drawdown on the plenum VOC concentrations over time.

TEST MEASUREMENT CONTROLS & DOCUMENTATION

The quality of the data collected as part of the test plan was intended to be sufficient to support engineering decisions affecting the design and installation of future VOC filtration systems. The applicable Quality Assurance Objectives (QAOs) identified in the existing WIPP Quality Assurance Project Plan for Volatile Organic Compound Monitoring were used for the VOC sampling/analysis portion of this test plan. Sampling and sample custody, analytical methodology, and data validation and management were applied using the same procedures and protocols required by the routine VOC monitoring program. Although these test data were not for compliance monitoring, they were intended for use in decision making, and the same principles were applied to samples and data produced under the GAC FRS test plan as are applied to compliance sampling.

Airflow measurements were performed or estimated using standard engineering methods and manufacturer-provided equipment specifications. The airflow data quality was commensurate with standard engineering measurement expectations, but airflow data for this test were considered to be estimated since no direct-reading flow rate instrumentation was installed.

Field measurements, such as platform scale readings, were conducted per manufacturers' instructions for the equipment. The platform scale was calibrated in accordance with the manufacturer's procedure using a method suitable to establish repeatable precision and linearity within the anticipated operating range. Accuracy was ± 0.5 kg over the range of measured values. Airflow measurements were estimated to be within 10% of actual flow rate. The VOC sample collection measurement and laboratory analysis accuracy levels for the test samples were found to be within the same range as the accuracy levels of the routine VOC monitoring program samples.

Measuring and test equipment (M&TE) used to verify instrumentation that is part of the installation was documented by the WIPP Metrology program to be in control at the time of use.
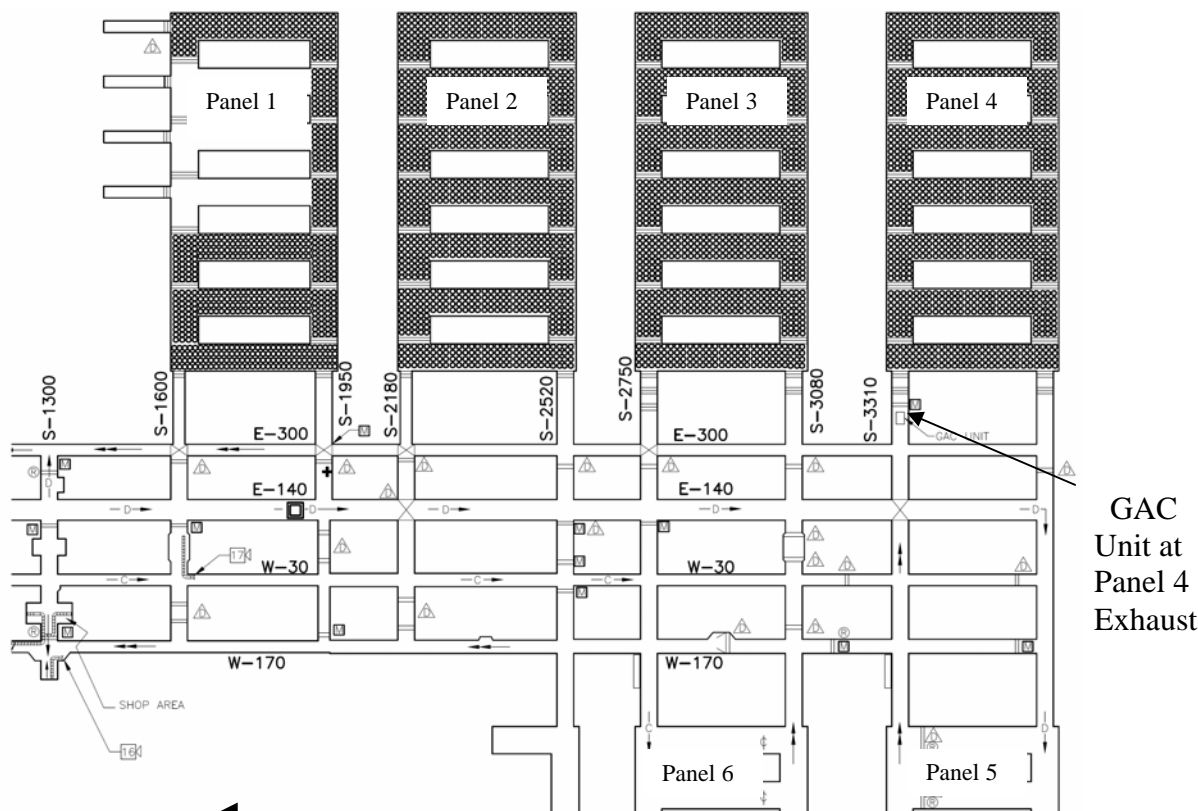
Fig. 1. Location of the GAC FRS in the WIPP Underground

TEST PERFORMANCE

The testing was performed on the installed GAC FRS unit while it was in operation. System airflow measurements were conducted while the unit was on the surface, but the initial mass (scale) determination was done underground *in situ* prior to startup. VOC sampling and periodic mass measurements occurred while the unit was operating underground.

The test was conducted in two parts:

- Reduction of data from sampling and analysis of the inlet and outlet air stream of the operating filtration system determined both the percentage reduction for the VOC of interest from the air stream, and, given the previously-measured airflow rate, determined an expected calculated mass loading on the GAC filter. The samples were collected in passivated SUMMA-type stainless steel canisters and transported to an offsite laboratory for analysis. The nominal airflow information was determined through pre-installation system testing.
- Mass measurement of the GAC filtration unit (gross scale weight indication) allowed an incremental determination of the mass change representing the loading (added mass) on the carbon filter as the system operated. The filtration unit was tared at the start of the test sequence (and at each filter change) using a platform scale staged under the unit. The total mass was measured *in situ* during each shift by observation of the remote scale indicator display when staff were available underground. At the end of the sequence (when the percentage reduction of CCl_4 through the filter approached zero and the rate of mass increase slowed noticeably), the endpoint mass less the tare mass measurement indicated a net total gain that represented the GAC filter loading at saturation.
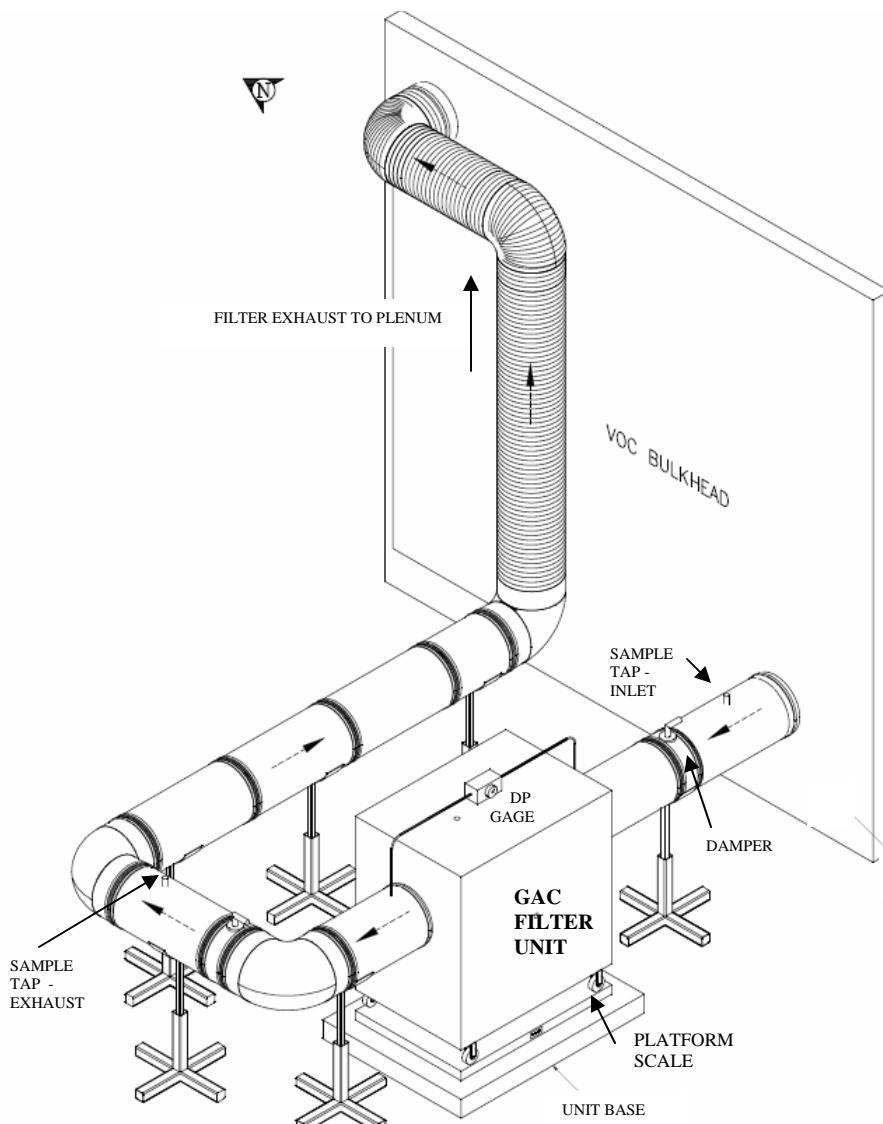
Fig. 2. GAC FRS in Panel 4 Exhaust

The test period ran from mid-February through March 2010. The initial filter was placed in operation on 12 February and was replaced on 26 February. The second filter was in place from 26 February through 11 March, and the third filter ran from 11 March through 18 March. The fourth and final filter in the test period was in place from 18 March through 30 March 2010.

The filtration system was operated continuously (168 hr/wk) for the duration of the test. Also, the filtration unit was operated at a nominal flow rate of 14.2 m^3 (500 actual cubic feet) per minute, re-circulating filtered air to a 45 m^3 (1,600 ft^3) plenum containing carbon tetrachloride (CCl_4) at an initial level of about 100 parts per million by volume (100 ppmv, or, 100,000 parts per billion by volume [ppbv]). Sample test ports on the inlet and outlet ducting of the filtration unit were designed to connect with the existing passivated canister collection units normally used for routine VOC sampling. The sample ports were at a slight negative relative pressure on the inlet side, and at a slight positive pressure of about 0.249 kPa (1" water gage), on the filtered outlet side. These conditions allowed operators to collect samples using existing VOC monitoring procedures. The filtration unit rested on the platform scale during operation, making mass measurements simple to obtain without shutdown and physical movement.

Sampling was performed using existing approved procedures within the process envelope also used to define compliance-related quality-controlled VOC air sample collection. The intent was to determine both the percentage reduction for the VOC of interest from the air stream (including relative percentage of the other VOC constituents), and, using the nominal airflow rate, to determine the expected calculated mass loading on the GAC filter.

The platform scale staged under the filtration unit was operated per the manufacturer's instructions. The net mass (incremental increase from the beginning conditions for each of the filters) was periodically determined from total mass readings taken *in situ*. At the end of the filter life (when the percentage reduction of CCl_4 through the filter approached zero), the mass measurement indicated a net total gain that represented the carbon filter loading. The fraction of the net mass loading that represented CCl_4 was determined by calculation of CCl_4 percentage in the plenum mixture from results of VOC analyses that included a number of other volatile organic compounds, known to also be present, collected in the passivated canisters. Since the ambient air moisture content was low (relative humidity ranging about 30% to 40%), no moisture effect corrections were applied [3]. Filter change out during the four filter runs and routine periodic GAC FRS maintenance were conducted under approved procedures and work control documents.

Additional information on CCl_4 removal efficiency by the filter was available from a handheld PID instrument operated by Industrial Hygiene staff. Although the sensitivity was much less than that obtained by an analyzed sample, the immediate feedback method proved to be effective in determining the filter maximum loading point using readings from system inlet and exhaust ducting sample ports.

The data collected consisted of:
- VOC concentrations (in ppbv) from the inlet and exhaust sides of the filtration unit ducting (typically sampled weekly, and at start of and end of filter life),
- filtration unit mass (kg) read periodically (typically daily),
- filtration unit differential pressure (inches water gage) read periodically (typically daily),
- plenum and inlet/outlet duct CCl_4 concentration (ppm) by PID instrument, read occasionally through filter #3, periodically starting with filter #4,
- the time and date of each of the data or samples collected.

The data were transferred to an Excel spreadsheet from the various raw reports (e.g., email, electronic analytical data deliverable files) segregated by filter, and the mass increase was tracked on graphical plots as data became available. (See Fig. 3.) By convention, PID-measured values will be reported as "ppm," and sample analysis-derived data as "ppmv" or ppbv." An overview of the test data collected is presented in Table I.

Table I. GAC FRS Test Data Summary

Sample Period	Data Type	Data Range	Purpose of Collection	Interface With	Data Usefulness
12 Feb 2010 through 30 March 2010	VOC concentration in air by lab analysis	2,760 to 198,000 ppbv CCl_4, other VOCs at lesser concentrations	Determination of the filter efficiency during system operation, determination of VOC constituent ratios.	Filter air flow rate, elapsed time for filter in service, internal ratio comparison.	Overall filter efficiency – marginally useful. Determining VOC ratios – very useful.
12 Feb 2010 through 30 March 2010	System airflow indication by differential pressure	0.162 to 0.224 kPa (0.65 to 0.90 inches water gage)	Verification that the filter is passing air satisfactorily, and that the flow rate is within nominal tested range, calculate VOC mass collected.	VOC concentration, by sample analysis or PID, elapsed time for filter in service.	Verification of filter flow rate – fairly useful. Calculating VOC mass collected – fairly useful.

Sample Period	Data Type	Data Range	Purpose of Collection	Interface With	Data Usefulness
12 Feb 2010 through 30 March 2010	System total mass (initial tare mass at 105 kg)	105 to 119 kg	Tracking the total mass on a time series returns the mass incremental gain per time period, and over the filter life.	Elapsed time for filter in service, divide total using internal ratio of VOCs to determine mass contribution of each.	Determining rate of mass gain slowdown – very useful. Determining individual VOC mass contribution – very useful.
18 Feb 2010 through 30 March 2010	System CCl_4 concentrations by PID	23.4 to 106 ppm	Determine safety-related CCl_4 concentrations in and around the GAC FRS.	System air flow, correlate with mass increase rate.	Determining filter efficiency for CCl_4 – very useful. Determining end-of-life – very useful.

DATA SUMMARY

The data used for assessment in this report are from four sets of filter installations. Each filter was run until measurements indicated that there was no more apparent removal of VOCs. The datasets did not all have the classic laboratory curve fit: for example, instead of exhibiting smoothly increasing mass values, there were reversals and sharp changes indicating that there was a source causing disequilibrium (Fig. 3). Several key parameters appeared to move consistently within expectations, however. The mass of CCl_4 removed is presented in the Table II summary and is derived from sample concentrations, the nominal flow rate, and a correction factor applied to reconcile the total filter mass with the CCl_4 portion of the calculated total VOCs removed. The actual filter run time did not necessarily reflect the filter life end point if the change out schedule fell on a day when support were not available. If the end point is taken to be the time at which incremental weight increase is not noticeable, the run period would be slightly shorter than was practically experienced.
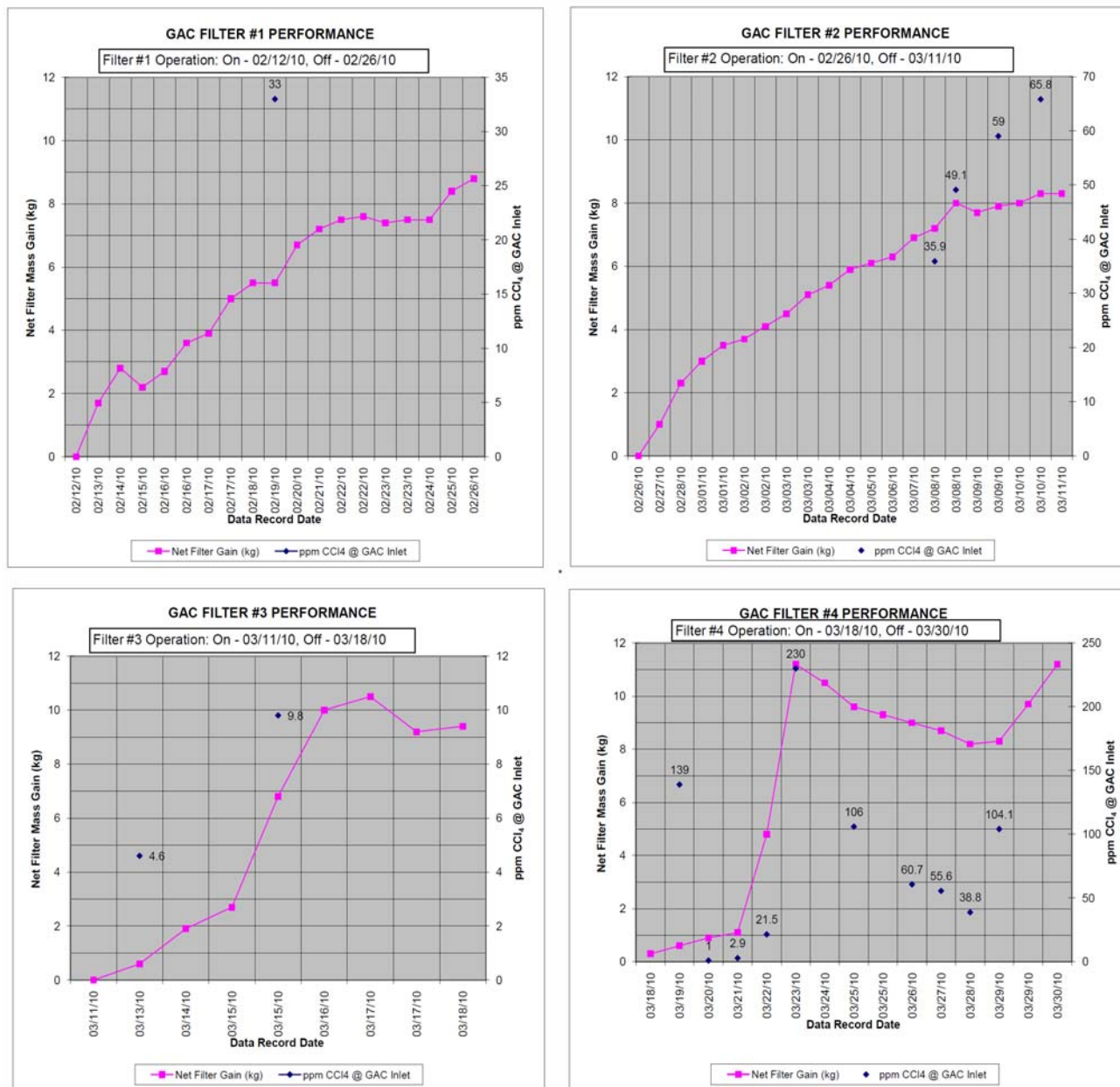
Fig. 3. Net Filter Mass Gain Plots

Although not a critical element, coordination of test data collection (airflow, mass increment, and inlet/outlet sampling) was scheduled to occur roughly on the same date to facilitate integrated time-series plots. The field data collected documented the following information:

- The mass of the newly installed GAC filtration unit read in tenths of a kg. (accuracy over the range of interest documented to ± 0.5 kg),
- Periodic measurements of the unit mass gain obtained (by subtracting the initial "tare" mass of the pre-operational system from the current operating system mass) along with the date and time of measurement, to determine the incremental increase related to VOC capture during operation,
- The increments recorded and graphed on a modified time series plot (data from roughly equal time periods) to determine the slope (mass capture rate) and expected VOC removal saturation point for the activated carbon filter.

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The analytical data collected documented the following information:

- • The inlet and outlet VOC (CCl$_4$) concentrations during filtration, determined for the initial startup period (within about an hour after a new filter was placed into service) by sampling. In addition, concentrations of periodic (weekly) and end-of-filter-life samples collected in a similar manner.

These periodic measurements were intended to provide a removal fraction on a time series that could be plotted to indicate a change in efficiency, and saturation point, as applicable. Given the unexpected plenum concentration variability, the schedule did not dictate a high enough sample frequency to track some changes, and the fact that samples could not be collected simultaneously diminished the reliability of quantitative conclusions drawn solely from that information. Table I gives a summary of the types and range of data collected during the test period.

In addition, using estimated filtration system airflow rates, the expected CCl$_4$ loading rate was calculated for the carbon filter. Due to the length of time between sample collection and analytical results, the variability in concentrations (documented by the more-frequent PID readings), and apparent removal efficiency fluctuations, a reasonably robust and timely loading rate estimate could not be made using only these data.

The introduction of the PID data-logging instrument allowed immediate and documentable measurement of total VOC concentrations from inlet and exhaust duct ports on the GAC FRS. These readings (Fig. 3, right scale), taken typically daily during routine rounds to inspect operating equipment underground, are indexed to CCl$_4$. It was observed that when the inlet/exhaust differential remained for several readings (days) at less than about 1%, the mass gain slowed and the VOC concentration in the plenum started to rise. This indicator set along with a net gain of more than eight (8) kg in the filtration unit experientially indicated that the filter was saturated.

In a separate measurement process using an existing sample tube installed directly into the plenum, the data collection mode on the PID instrument was used on several occasions to log interval concentration changes in the plenum between the bulkheads being treated with the carbon filtration system. (See Fig. 4.)
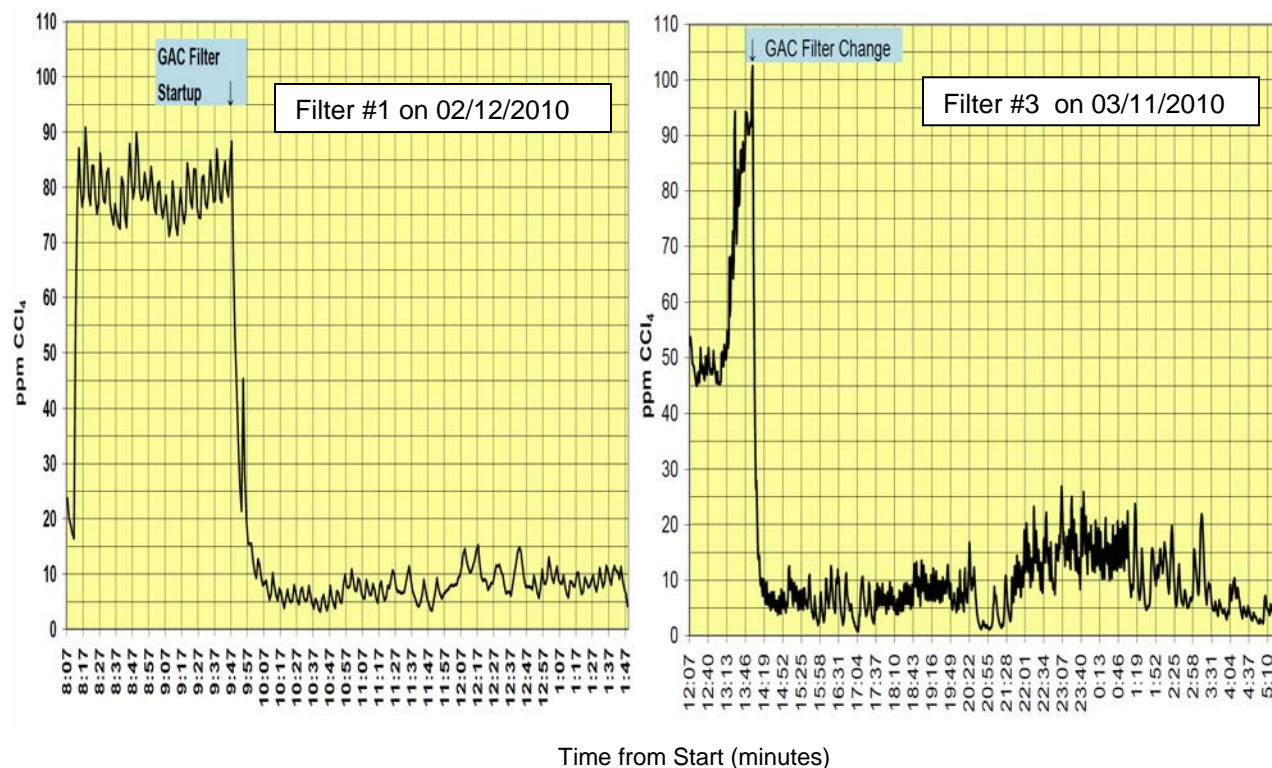

Fig. 4. Concentration Changes During New Filter Installation

OPERATIONAL EXPERIENCE & EFFICIENCY

In general, the observed filter maximum saturation loading (for the four filters tested) was reached at an average of eight days' run time, although the filter was not necessarily changed out immediately at the end-of-life point. This maximum was achieved at a starting concentration of between 20 and 120 ppm CCl_4 as measured with a PID in the plenum between the bulkheads. The observed initial activated carbon removal efficiency was about 90 percent, but that fell within several days to less than 40 percent. There seemed to be some uneven filtration (adsorption/desorption cycles) in that the efficiency appeared to vary up and down after the initial loading phase. The filter appeared to stop gaining mass steadily at lower than a 1 percent sustained removal efficiency.

Streamlining regular filter maintenance appears to be linked to stabilization of the VOC concentrations in the plenum as much as any other factor. If there is an expected loading cycle (e.g., reaching saturation weekly), the schedule could be set to change the filter on a specific operationally low-impact day, and an adequate store of filters and expended-filter containers could be planned and managed. The sample collection schedule would be reduced to periodically verify that the VOC constituent ratios are reasonably similar, and PID readings showing low removal efficiency (several sequential readings of less than 5% removal efficiency) along with mass gain above 8 kg would initiate the filter change out. Data collection would be limited to mass gain, airflow indication (filter pressure differentials), and PID inlet/exhaust readings during operation.

DATA ASSESSMENT

If calculated without correction to normal temperature and pressure, the system design conditions as described in the test plan (0.189 m^3/sec [400 ACFM] continuous filter flow rate at 1 ppmv CCl_4) would have resulted in an expected maximum incremental filter mass increase of 0.657 kg of CCl_4 per 168-hour week. Given those parameters, weekly measurements would be the minimum starting period for detectable mass increment determination. For a 45 kg (100 lb) filter containing 38 kg (84 lbs) of activated carbon at 50% filter mass loading before saturation, the expected maximum total load would be 19 kg during about 29 weeks of operation [3].

Actual concentrations measured in the plenum before system startup showed an initial CCl_4 concentration near 100 ppm, and, as expected, a shorter interval was needed to reach the saturation point. As had been postulated for this closed space, since the CCl_4 concentration between the bulkheads was nearer to 100 ppm (100,000 ppb) than the system design basis 1 ppmv level, the removal rate was proportionately more rapid. In this case, a 19 kg loading (necessitating a filter change) could have occurred within three days at that concentration. The initial drawdown stabilized the concentration (relatively speaking) at about 10 ppm after system startup.

The portion of the test evaluation that used sample data gave mixed results owing to the concentration fluctuations in the plenum. The changes were sufficiently variable to cause apparent negative removal efficiency indications when the inlet and outlet samples, collected about ten minutes apart, were compared. Additionally, the actual filter net mass was more than a factor of two higher than the net mass calculated using raw sample data and the air flow estimates. A derived correction factor applying the ratio of VOC constituents based upon sample analysis to the observed mass from the platform scale appeared to be applicable to the four filters examined, and allowed an estimate of the total CCl_4 removed per filter. This factor was applied to the sample-derived individual VOC values to "normalize" that data to the filter mass-increase-based gross measurements.

The actual performance was consistent with the higher concentration estimates anticipated in the test plan. Although the initial plenum concentration was logged at near 100 ppm , the post-drawdown "steady-state" concentration in the plenum (approximate inlet concentration) after less than an hour of operation was less than 10 ppm for the first filter. (See Fig. 4.) The filter mass increase from all filters (mostly VOCs, as identified by the sample results) appeared to be approximately 8 kg at the point of maximum load (saturation). It was estimated that about 55% of the observed mass increase (based upon VOC sample analyses) was due to CCl_4, so it would follow that typically about 4.4 kg of CCl_4 per filter was being removed from Panel 4. At a weekly filter change schedule (which appeared at first to be a reasonable cycle) the removal of CCl_4, although significant, would still fall somewhat short of the initial target of 6 kg/ week or more removal rate given an average 100 ppbv CCl_4 actual concentration (23 kg/wk in mine exhaust) in the E-300 drift (Fig.1).

Using results from a concurrent sampling effort [4] to define the before-and-after CCl_4 mass emission rates attributed to specific waste-containing panels as air flowed by them, the estimated overall filter system effects were estimated and tabulated in Table II.

Table II. GAC FRS Effects

Filter No./Run Dates	Total gain (kg)	Estimated CCl_4 Removed (kg)	Estimated Panel 4 CCl_4 Emissions (kg)	Estimated WIPP mine Air Emissions (kg CCl_4) {per SAP Panel total [4]}	Potential Mine Air CCl_4 Percentage Reduction
#1: 02/12/10 – 02/26/10: **14 days**	8.8	2.29 (raw) **4.93** (estimated normalized)	about -**1.1 g/min** 14 dy*24hr/dy*60 min/hr= **22.2**	**122**	**4.0%**
#2: 02/26/10 – 03/11/10: **13 days**	8.3	1.61 (raw) **4.69** (estimated normalized)	about -**1.1 g/min** 13 dy*24hr/dy*60 min/hr= **20.6**	**114**	**4.1**%
#3: 03/11/10 – 03/18/10: **7 days**	9.4	1.40 (raw) **4.80** (estimated normalized)	about -**1.1 g/min** 7 dy*24hr/dy*60 min/hr= **11.8**	**70**	**6.9**%
#4: 03/18/10 – 03/30/10: **12 days**	11.2	3.94 (raw) **6.50** (estimated normalized)	about -**1.1 g/min** 12 dy*24hr/dy*60 min/hr= **19.0**	**200**	**3.3**%
SUMMARY: 45.2 days GAC FRS run time	37.7 total, 9.4 average	20.9 total, 5.2 average (estimated normalized)	73.6 kg estimated total Panel 4 emissions over a 45 day period	506 total (SAP sample data calculation) over a 45 day period	4.1% filter average (for cumulative totals over a 45-day period)

SYSTEM EFFECTIVENESS

The system appears to demonstrate the proof-of-principle effectiveness requirement stated as a primary objective in the test plan: the information collected during the testing should also be useful in developing operating parameters for a next-generation design.

In meeting this objective, the tests provided data to:
- Estimate the removal efficiency of the system filter by comparison of the inlet and outlet duct CCl_4 concentrations.
- Estimate the total mass of CCl_4 removed (filter-captured) in comparison to the typical mass of CCl_4 in mine ventilation exhaust air during a specific period of time (Table III),
- Define a typical operating period when the outlet duct concentration has increased to be approximately equal to the inlet concentration, showing that the filter has reached its adsorbent capacity, and
- Determine a typical net mass adsorbed at saturation.

Table III summarizes the objectives and the test data demonstrating satisfaction of those objectives.

Table III. GAC FRS Test Objective Result Summary

Objective to be Met	Method of Satisfaction	Supporting Data Results	Objective Satisfaction	Constraints
Define GAC CCl_4 removal efficiency	Compare cross-filter concentrations (sampled inlet minus exhaust)	Removal efficiency – At system start : 90.4% Overall Average:27.7% Nominal FRS filter flowrate is 0.236 m³/sec (500 ACFM)	Efficiency defined: Effective removal, objective met	Observed variability precludes general application of an average removal efficiency.
Define total mass of CCl_4 removed compared to CCl_4 exhausted from mine	Estimate and sum CCl_4 removed by the GAC filters over a given time period, estimate CCl_4 in mine exhaust during same time.	Estimated total CCl_4 exhausted: 506 kg Estimated total CCl_4 removed: 20.9 kg (tallied from the SAP)	Mass removed was calculated, mass exhausted calculated, but variables were not sufficiently controlled to result in a satisfactorily robust result.	The actual CCl_4 in each filter was not quantified after removal, and the CCl_4 exhaust rate is highly variable resulting from changing mine operations air flow needs.
Define a typical operating period for maximum filter loading.	Determine time of operation from start to saturation based upon operating indicators.	The first four filters averaged about eleven days between changes. The shortest loading time was six and a half days: the longest was fourteen days (including two days' change out delay)	The objective was met for the core test period. Observations of filter load rate after some ventilation changes show a much longer time-to-saturation, corroborated by observation of lower average plenum CCl_4 concentrations.	If the GAC filtration were acting on higher CCl_4 levels (>20 ppm), the loading rate was observed to be faster. Determining the average concentration in the air being treated is an important factor in defining a filter operating period. System design constrains flowrate to a nominal 0.236 m³/sec (500 ACFM) for GAC.
Define a typical net mass of CCl_4 adsorbed at saturation.	Determine the mass of CCl_4 in each filter at removal, and calculate a typical mass per filter.	Using sample data, an average CCl_4 mass was determined, using a correction factor to normalize the observed scale mass to calculated mass retention, to be 5.23 kg/filter.	This objective was satisfied by calculations: again, the CCl_4 concentration variability introduced uncertainties that resulted in a less-defined result.	The nominal air flow times sample mass per volume for time of operation returned a mass result much lower than the observed scale mass increase. No technical reconciliation was determined.

The data support the conclusion that the GAC system as tested is effective at removing CCl_4 from the air. The test results may justify continued development of a more robust VOC removal unit. Applied effectiveness in comparison to overall mine air concentrations, however, appears to be contingent on contaminant removal from behind barriers that intercept and "hold up" the VOCs migrating from the waste emplacement towards the ventilation stream. Reduction of VOC concentrations behind the barrier separating the plenum from the mine ventilation stream implies that leakage around the barrier would have a lesser effect when the GAC FRS were operating than it would from a higher concentration without a removal system in place.

Any system installed on Panel 4, no matter how efficient, would have an apparent maximum reduction effect on overall mine air limited by the relative Panel 4 contribution to CCl_4 in the ventilation air. This has been calculated to be on

average approximately 27 percent per the SAP data collected to date. It appears that, given a CCl_4 filter capture efficiency of about 40%, and the Panel 4 CCl_4 contribution of about 25% of overall mine air concentrations, for an optimized installation at least ten percent of the overall mine air CCl_4 could be removed if all emissions from Panel 4 could be processed through the GAC FRS. The higher the relative contribution of Panel 4 to the overall mine air concentrations, however, the more effective a Panel 4 filtration system would be on mine ventilation as a whole. For the Filter #3 operating period, for example, high removal rates and relative Panel 4 contribution to CCl_4 in mine air appear to make the calculated filter removal rate about 7% of the total CCl_4 in mine air. The observed variability of CCl_4 concentrations in mine exhaust air, however, precludes a definitive demonstration that this is the normal case.

The system as tested appears to provide local capture of VOCs, including CCl_4, with discernable effect. If different media were to be used, some measure of both efficiency and retention of non-VOC airborne constituents, such as water vapor, should be defined for each given medium used with this or a similar system. The tracking of both mass increment increase (with the assumption that VOCs account for the added mass) and VOC concentration differential across the filter unit appear to be simple and effective maintenance control indicators.

Operation of this or a similar system appears to be relatively simple once the installation is complete. Routine daily checks and a scheduled filter change out cycle would streamline and optimize the operations to have minimum interfacing operational impact. Selection of a non-combustible filter medium would simplify the surveillance and safety constraints applicable to a carbon filter in place underground. The trade-off between filter efficiency and combustibility would need to be evaluated, but those factors certainly are important operational considerations.

The combined efficiency and capacity of the carbon filter medium appears to be most effective at higher VOC concentrations. In practice, filtration should be provided at the higher concentration of a given panel intake or exhaust drift.

REFERENCES

1.   CATC Technical Bulletin. "Choosing an Adsorption System for VOC: Carbon, Zeolite, or Polymers?" EPA-456/F-99-004, United States Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, (May 1999)

2.   L.A. JONAS, E.B. SANSONE, T.S. FARRIS, "The Effect of Moisture on the Adsorption of Chloroform by Activated Carbon," Am. Ind. Hyg. Assoc. J., 46(1):20-3, (January 1985)

3.   C.L. CHUANG, P.C. CHIANG,*, E.E. CHANG, "Modeling VOCs Adsorption onto Activated Carbon," Chemosphere 53 17–27, (2003)

4.   E. PICAZO, E. D'AMICO, "Sampling and Analysis Plan (SAP) for Determination of VOC Source Locations and Relative Contributions in the Disposal Circuit Ventilation Air at WIPP," (INTERNAL WIPP REPORT IN PROGRESS), concurrent unpublished internal document (2010)