In 2017, an effort was undertaken to develop a protocol for testing and evaluating the performance of commercial, service-based, air treatment technologies used to treat low concentration volatile organic compounds (VOCs/odors). A protocol was developed (STANDARD PROTOCOL 2018) to determine the efficiency (efficacy) and safety (amount of residual or secondary/daughter products) of treatment technologies. Two air treatment technologies, Carbon Filtration and the BioSweep Treatment (BST) were selected to validate the STANDARD PROTOCOL 2018. This validation testing is summarized in a technical paper, which was authored by Mr. Steven Irvin and Mr. Richard Griffith. Mr. Irvin is Principal for Acuity Environmental Solutions, LLC and has a degree in Chemical Engineering from Oregon State University. He has over 30 years of experience in the environmental field treating soil, groundwater and air (vapors). Mr. Griffith is the owner of Workplace Safety & Health Company Inc and has a degree in Environmental Health from Purdue University and is a Certified Industrial Hygienist (CIH) with over 30 years in the hygiene field, with memberships in the American Board of Industrial Hygiene (ABIH), American Industrial Hygiene Association (AIHA), and American Society of Safety Engineers (ASSE).

The development of the STANDARD PROTOCOL 2018 was a lengthy and exhaustive process, as it was designed to create a duplicable testing procedure for all forms of air treatment technologies. Vehicles were selected as the test chambers as they have all of the same materials typically found in buildings (rubber, vinyl, leather, plastics, cloth, electronics etc.) simulating real-world applications of air treatment technologies. Formaldehyde was selected as a source VOC since it is found in many treatment applications and is has been wrongly assumed that it is a daughter product created by advanced photocatalytic oxidation. While the technical paper was developed to validate the protocol, ***the results also clearly demonstrated the efficacy and safety of the BioSweep Treatment (BST) process.***

The BST Process combines Advanced Photocatalytic Oxidation (APO) and Carbon Filtration, which differentiates itself from Ozone and other APO treatments. ***The BST process fully oxidizes the environment, thus breaking down VOCs completely which prevents daughter products from being created.*** The created gasses are also fully dismantled during the treatment process.

In the attached Executive Summary, the following conclusions were made:

- ***The BioSweep Treatment Process reduced VOC's by 99%*** (Page vii: Performance of Technology).

- ***The BioSweep Treatment Process reduced the formaldehyde levels by 95%.*** (i.e. no formaldehyde was produced, only broken down). The results from the Technical Paper proved conclusively that the BioSweep Treatment Process not only fails to create Formaldehyde, it rapidly dismantles it in all cases (Page vii: Conclusions, fourth bullet).

- ***The BioSweep Treatment Process produced no daughter products from the formaldehyde*** or any secondary materials found in the test vehicles, ***as all compounds tested under USEPA TO-15 were below screening levels.*** This test is the standard used for indoor air quality testing by the U.S. Environmental Protection Agency (Page vii: Conclusions, fifth bullet).

- ***The results from the technical papers found there was no noticeable material degradation*** in any of the test vehicles following the BioSweep process (Page viii: Recommendations: last bullet).

The conclusions in the following paper are based on the performance of the BioSweep Treatment process and comparable results cannot be assumed for any other APO equipment unless it is tested under the STANDARD PROTOCOL 2018.

AN APPLICATION OF THE STANDARD PROTOCOL FOR TESTING AND EVALUATING THE PERFORMANCE OF COMMERCIAL, SERVICE-BASED, AIR TREATMENT TECHNOLOGIES USED TO MANAGE LOW CONCENTRATION RESIDUAL VAPOR PHASE VOLATILE ORGANIC COMPOUNDS

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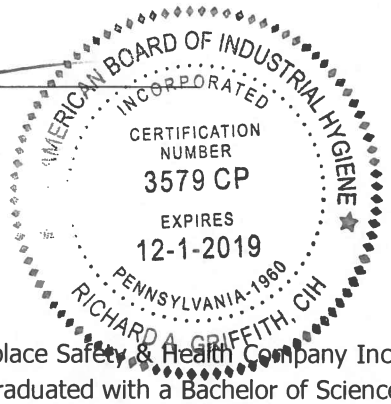

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EXECUTIVE SUMMARY

Currently, the authors are not aware of a published ASTM International Standard for evaluating the treatment of vapor-phase volatile organic compounds using commercial, service-based, air treatment technologies within finite-spaces. This fact may partially be due to the variability of commercial technologies and applications, and the number of controlled and uncontrolled variables that must be managed to collect consistent data to support concise and repeatable conclusions. The *Standard Protocol for Testing and Evaluating the Performance of Commercial, Service-Based, Air Treatment Technologies used to Manage Low Concentration Residual Vapor Phase Volatile Organic Compounds* (Standard Protocol 2018), dated August 24, 2018 was developed to address the lack of a specific, industry-accepted, testing protocol.

Development of the Standard Protocol 2018 was focused on the following critical evaluation elements:

1. The results of vapor-phase analytical testing will be compared to United States Environmental Protection Agency (USEPA) May 2018 Residential Air Regional Screening Levels; Target Indoor Air Concentrations for Non-Carcinogens [Total Hazard Quotient = 0.1]; and Target Indoor Air Concentrations for Carcinogens [Total Cancer Risk = 1E-06].
2. Vapor samples will be collected and analyzed using the USEPA TO-15 test method, and samples will be collected before and after treatment. The TO-15 test method is an USEPA recognized standard for 62 potentially harmful volatile organic compounds present in residential environments.
3. Real-time monitoring will be used to continuously monitor changes to the source VOC concentrations used for testing.
4. The Standard Protocol 2018 includes flexibility and scalability specific to different technologies, based on the judgement of a knowledgeable professional, which allows for modification of the sampling procedures where appropriate.
5. Post treatment monitoring of the TREATMENT CELL must be included to evaluate potential rebound or changed equilibrium conditions.

The following report was prepared to independently evaluate the applicability of the Standard Protocol 2018 by evaluating two (2) commercial treatment technologies used for reducing the concentration of volatile organic compounds (VOCs) in a temperature and humidity controlled, finite-space, test vehicle. The first technology uses filtration/adsorption and the second technology uses vapor-phase oxidation followed by filtration/adsorption. Formaldehyde was selected as the source VOC for use during the evaluation of each candidate technology.

The Standard Protocol 2018 was developed to consistently evaluate the following aspects of a candidate technology:

- Time related to the application of the technology (minutes, hours, days, etc.);
- Performance of the technology (vapor-phase analytical results from before and after treatment);
- Treatment delivery mechanisms (forced air; diffusion; suction);
- Constants evaluated across all technology assessments (controlled VOC source and temperature).

The first technology to be evaluated is marketed under the name PowerMaxx and uses a one-step process to draw air (vapors) into a stainless-steel vessel and pass that air (vapors) through commercial granular activated carbon (GAC) before discharge of the treated air back into the test vehicle atmosphere, with the objective of adsorbing vapor-phase contaminants onto the GAC.

The second technology to be evaluated is a two-step technology that is marketed under the name BIOSWEEP Treatment (BST). The first step in the process uses vapor-phase photocatalytic oxidizers produced inside of the BST vessel and distributed into the atmosphere with a powered blower. The photocatalytic oxidation process is subsequently followed by commercial granular activated carbon (GAC) adsorption. For the purpose of this technology evaluation, a PowerMaxx unit was used for the second step in the BST process.

The Standard Protocol 2018 [Appendix A, Section 6], describes requirements for a CONTROL CELL to be used for direct comparison to a "no treatment" environment. For this report, the authors performed two tests (both in a Toyota Corolla). The source of formaldehyde was placed on a cotton cloth, which was mounted over the dashboard heating, ventilation and air conditioning (HVAC) vents. The cotton cloth containing the formaldehyde [formalin solution], was removed from the test vehicle after 10 minutes. This is consistent with the approach used for technology testing discussed in this report. In the first test the HVAC system was operated for the duration of the assessment timeframe of 180 minutes, allowing the test vehicle HVAC system to dilute the atmosphere inside the test vehicle with air from outside the test vehicle. In the second test the HVAC was deactivated at the time the source was removed and data were collected for 180 minutes. These data were used to represent results from a CONTROL CELL for direct comparison with the technology tests presented in this report. The concentration of formaldehyde was monitored beginning with a starting concentration of approximately 20 ppm that decayed to approximately 2 ppm over a period of 180 minutes. Note the protocol used to assess the CONTROL CELL allowed for data collection over 180 minutes, however the treatment technologies were evaluated over shorter time periods based on manufacturer's recommendations.

The evaluation of the PowerMaxx technology produced evidence supporting the following observations:

- *Time of Application*. The process of capturing the atmospheric vapors from within the test vehicle and then directing those vapors into the PowerMaxx unit is not as efficient as many other treatment technologies. This assessment is predicated on the author's observations during the designed 135-minute evaluation specified by the technology supplier for the test.

- *Performance of Technology*. Reduction of formaldehyde concentrations in the test vehicle were dependent on how "new" or "clean" the carbon was inside of the PowerMaxx. Additionally, based on a limited literature search, effective formaldehyde treatment using granular activated carbon requires the use of "specially impregnated, coconut shell-based activated carbon". The literature indicates that there are numerous other compounds that will be preferentially sorbed to the carbon surfaces inside of the PowerMaxx. The reduction in source VOCs when compared to the CONTROL CELL produced minor benefits when evaluated for the technology owner's specified treatment time.

- *Treatment Delivery Mechanism*. Formaldehyde is a small molecule that can adhere to various surfaces within the test vehicle. Observations from the tests evaluated by the authors indicate the need to distribute the treatment technology into all "soft surfaces" [e.g. upholstery, head

liners, carpet]. The better the technology is distributed into the atmosphere, on hard surfaces [e.g. leather, wood, plastic, vinyl], and into the soft surfaces, the better the observed treatment results. The design of the PowerMaxx unit requires the vapors from within the test vehicle to be drawn into the treatment unit. Therefore, formaldehyde molecules that are adhering to the soft surfaces in the test vehicle will resist being drawn into the PowerMaxx for treatment. The authors recognize this issue will be a challenge to all forms of treatment technology that are not intentionally placed in intimate contact with formaldehyde molecules that adhere to soft surfaces.

- *Constants Applicable to Each Technology.* The most significant observation related to the PowerMaxx unit is the reduction of petroleum based organic compounds that are likely to be attributable to residual fuel from the test vehicle's exhaust that affects the atmosphere around the exterior of the test vehicle. This is the same atmosphere that is drawn into the test vehicle as part of the HVAC operation during testing. The analysis of the test vehicle atmosphere using the TO-15 test method provides evidence to support this observation.

The evaluation of the BioSweep Technology produced evidence supporting the following observations:

- *Time of Application.* The most significant observation related to the BST is the rapid reduction of formaldehyde measured in the atmospheric vapor within the test vehicle as the BST is deployed. Each test of the BST produced an immediate drop of the vapor-phase formaldehyde concentration to below the detection limits of the meters used during the evaluations. This response was consistently observed within the first ten minutes of BST operation. The formaldehyde concentration remained below the meter detection limits during the entire length of the BST evaluation period. Dräger tube samples were collected to confirm that the formaldehyde meters were reporting accurate responses. The rapid reduction of formaldehyde concentrations within the test vehicle produced consistent evidence that oxidation technology that includes a rapid form of deployment (fan or blower to rapidly disperse the oxidizers into the atmosphere) will perform faster than technology that attempts to extract and treat, or basically turnover or exchange, the atmospheric vapors within the test vehicle. This assessment is predicated on the author's observations during the designed 135 to 140 minutes evaluation timeframe specified by the manufacturer for the test (total times varied due to field sampling activities).

- *Performance of Technology*. The primary objective of the Standard Protocol 2018 is to evaluate the ability of a treatment technology to destroy, remove or otherwise eliminate the source VOC from within the test vehicle. Generally, within the first five to ten minutes of initiating BST operation, the concentration of the formaldehyde source VOC vapor inside of the test vehicle is consistently below the Extech meter detection limit of 0.1 ppm. This observation equates to a source VOC reduction greater than 99% in the vapor-phase.

- *Treatment Delivery Mechanism*. As noted during the evaluation of the overall performance of the BST, disbursement of the oxidizers into the test vehicle is more effective than attempting to extract, treat and replace the vapors inside of the test vehicle. An issue observed during the evaluation of the BST is the persistence of formaldehyde molecules to generally adhere to soft surfaces inside the test vehicle. These residual, untreated formaldehyde molecules establish low concentration equilibrium with the vapor inside the test vehicle after completion of the oxidation step for the BST. The authors observed a low concentration increase of residual formaldehyde

after the oxidation portion of the BST process was terminated. The formaldehyde concentrations detected after the BST process was completed ranged from below the Extech meter's detection limit of 0 ppm to a high of 1.00 ppm[1]. This residual value is less than 20% of the residual value observed in the CONTROL test, and 80% less than the starting source VOC concentration.

- *Constants Applicable to Each Technology*. The authors observed the same reduction of petroleum based organic compounds that are likely attributable to residual fuel from the test vehicle's exhaust that affect the atmosphere around the exterior of the test vehicle. Additionally, with both technology evaluations, there are generally twelve to fifteen organic compounds that are consistently detected in atmospheric vapor collected from each test vehicle and analyzed using the TO-15 test method. These compounds were detected in micrograms per cubic meter of vapor ($\mu g/m^3$). These detections are below US Environmental Protection Agency (USEPA) target indoor air concentrations for carcinogens and non-carcinogens and resident air regional screening levels.

The following conclusions were made during this study:

- The Standard Protocol 2018 provides an appropriate method to evaluate the two selected air treatment technologies: adsorption/filtration and oxidation/adsorption/filtration. This process includes using the EPA indoor air screening levels to evaluate secondary or daughter products that may be observed during the treatment (Refer to Section 2.3).

- An automobile used for the test vehicle was beneficial to the study as it allowed the authors to collect vapor samples to evaluate the treatment technologies for the production of degradation or daughter products included in the list of analytes for the TO-15 analytical method, given the variety of construction materials (i.e. plastics, adhesives, upholstery, carpet, foam, etc.) present within that space.

- The formaldehyde concentrations observed during the Power Maxx evaluation were generally within 1 ppm of the CONTROL CELL decay rates. The average PowerMaxx treatment reduced the formaldehyde concentration by approximately 20% to 30% when compared to the CONTROL CELL decay rate over the full length of the test (see Figure 5).

- The average BST evaluation reduced the formaldehyde concentration by approximately 19 ppm during the first five minutes of operation, which equates to a reduction of greater than 95% of the source VOC (see Figure 11).

- The testing indicated that neither treatment technology produced exceedances of EPA residential screening levels for the 62 analytes included in the TO-15 analysis. However, in one of the tests it appears that low level hydrocarbons may have been introduced into the test vehicle through the HVAC system, resulting in detections both before and after testing.

- A knowledgeable professional will be able to duplicate these results as well as adopt the Standard Protocol 2018 to evaluate other commercial air treatment technologies (i.e. ionizers, masking agents, oxidizers, etc.).

[1] The OSHA PEL for formaldehyde is 0.75 ppm. So theoretically, if the concentration of formaldehyde is not reduced to below the PEL, an occupant in the test vehicle could have an exposure that exceeds the OSHA PEL-TWA during an 8-hour drive in the car.

The following recommendations were made to improve the study:

- The authors recommend modifications to the Standard Protocol 2018 to include the replacement of the Extech meter with a Gasmet DX4040 Portable Ambient Air Analyzer. This meter can measure the formaldehyde concentrations from 0 to 50 ppm used as the VOC testing source, but also can monitor formic acid and carbon monoxide to further allow for a mass balance to be completed during the test to demonstrate decomposition of the source VOC by the oxidation process.

- The authors recommend the Standard Protocol 2018 be evaluated with the source VOC present during the full scope of testing.

- The authors recommend the Standard Protocol 2018 be evaluated with the test vehicle off and no HVAC in operation.

- Other VOC's should be considered for the source VOC in this protocol.

- Consider re-evaluating the PowerMaxx Technology using Formasorb as the source of carbon (Formasorb is distributed by Barnebey Sutcliffe). Per the manufacturer's literature, Formasorb has been specifically formulated to improve treatment efficacy when applied to a formaldehyde impacted atmosphere.

- Samples of wood block, colored fabric, and carpet samples were evaluated during some of the preliminary testing used to design the Standard Protocol 2018. The field technicians did not visually observe differences between TREATED and CONTROL samples. Specifically, the technicians did not observe changes, such as discoloration, bleaching, fading or blanching of the TREATED samples. Further research will be needed to develop measurement tools and evaluation procedures for future testing.