



**BSR/ASHRAE Addendum c to  
ANSI/ASHRAE Standard 145.2-2016**

**Public Review Draft**

# **Proposed Addendum c to Standard 145.2-2016, Laboratory Test Method for Assessing the Performance of Gas- Phase Air Cleaning Systems: Air Cleaning Devices**

**First Public Review (June 2024)  
(Draft shows Proposed Changes to Current Standard)**

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**(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)**

## FOREWORD

*The air processed by building HVAC systems typically contains a variety of compoundseontaminants in gaseous form. The concentrations of these compoundseontaminants may vary from trace amounts in most cases to the toxic levels that can be encountered near a spill or other extraordinary event. Whenever gaseous compoundseontaminants reach unacceptable levels, or may be expected to reach such levels, air cleaning may be used to improve the usability of the space or to protect the building occupants, the HVAC system components, or the contents of the building. These concerns exist not only for commercial buildings but for industrial workspaces as well.*

*This standard provides a performance test method both for individual air cleaners and for complete devices designed to be used for full-scale commercial in-duct gaseous- compoundseontaminant air cleaning.*

*This standard describes a test procedure with quality-control constraints to measure percent removal efficiency for a relatively low concentration challenge and by-product production levels of gaseous-compoundseontaminant removal devices when challenged under steady-state conditions. ~~The corrected efficiency,  $E_c$ , adjusts the efficiency for the challenge gas to account for the level of by products created.~~ This removal efficiency is intended to be used for the  $E_f$  required in the IAQ Procedure of ANSI/ASHRAE Standard 62.1. After the low concentration efficiency test, the procedure moves to either an extended low concentration test period or to a removal capacity test. The extended low concentration efficiency test is intended for EAC (non-sorbent devices) to show longer term stable performance. The capacity test is designed to simulate the capture performance of commercially available sorbent-based HVAC filters under controlled, representative conditions. Sorbent-based air cleaners often have a high removal efficiency initially but lower efficiency over time. The capacity test allows comparison across sorbent air cleaners. This test could be applied to other devices that have good efficiency at high concentrations.*

*The air cleaners to be tested using this standard are intended to remove gaseous compoundseontaminants that are present at low-to-modest levels and nuisance odors, thereby protecting building occupants, contents and processes, and reducing corrosion. The test end-point may be a chemical breakthrough that exceeds a minimum removal efficiency or a time limit. This test may be used to evaluate filters/devices for use in a building designed and/or operated according to the ASHRAE Standard 62.1 IAQ procedure. This test method is not intended to test air cleaners whose function is to protect against extraordinary events producing gaseous chemicals that are immediately threatening to the health of building occupants.*

*A companion small-scale, low-flow-rate version of this test procedure—ANSI/ASHRAE Standard 145.1, *Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Loose Granular Media*—provides comparable sorptive granular media challenges at a much lower nominal flow rate of 1.7 m<sup>3</sup>/h (28.32 L/min, or 1.0 ft<sup>3</sup>/min). This smaller scale provides a lower potential operator exposure and, with its much smaller footprint, is much more amenable to local exhaust venting and allows relatively easy cleanup. Method 145.1 does not apply to EAC.*

*The test challenge compoundseontaminants used may be hazardous, so the safety of those conducting the tests is of paramount importance. The primary personal hazard associated with the test method is*

*inadvertent inhalation. This procedure incorporates steps designed to reduce personal inhalation exposures, and these should be followed carefully. Merely following these steps does not, however, ensure safe operation. Each test organization is responsible for training, equipping, protecting, and monitoring the exposure of its personnel.*

*The laboratory test apparatus, equipment, test protocol, quality control guidelines, and equipment calibration recommendations provided are intended to achieve repeatability within  $\pm 10\%$  of the measured value. Where possible, the method specifies the performance required of hardware and instrumentation rather than prescribing the specific characteristics of these items in detail.*

*This test method was not developed to allow accurate test chemical measurement from saturated airstreams, so water scrubbers and similar technologies cannot be tested by this method.*

*The testing under this methodology can be conducted by modifying (e.g., adding temperature and relative humidity (RH) control and instrumentation) some large-scale rigs designed previously for testing per ANSI/ASHRAE Standard 52.2, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size. This adds versatility to the apparatus, allows switching back and forth between particle and gas testing, and increases the overall testing cost-effectiveness. Thus, many of the requirements for Standard 52.2 are retained for this gas cleaner method and are cited by reference to this earlier document, rather than repeating them verbatim. Additionally, some characterization testing, such as challenge compound~~contaminant~~ dispersal uniformity ahead of the test substrate, if previously conducted for Standard 52.2 and found to be acceptable prior to the gas-phase testing, is accepted as sufficient for the gas testing of this standard as well.*

*The most useful performance data for gaseous-compound~~contaminant~~ air-cleaning devices are those obtained at the design air-flow rate when challenged with the chemical contaminating the space and at the use conditions. The results of such a test best determine the air cleaner lifetime that can be expected. Many applications require control of mixed compound~~contaminants~~ present at very low levels for extended periods (months), and in this case, the test becomes excessively expensive. On the other hand, a test can be conducted according to this standard at a fixed flow rate, temperature, RH, and at an elevated challenge concentration relative to expected use levels. Such a test is shorter, reducing testing cost, but the test results are directly useful only for ranking different air cleaners. A substantial body of theory and data supports extrapolation of breakthrough times for many physically adsorbed hydrocarbons across several orders of magnitude in concentration. Such extrapolation is not generally accepted for chemisorbed chemicals such as the acid gases or for the performance of EAC.*

*Test challenge concentrations and conditions allowable under this method are presented in detail in the main sections of this standard.*

## **1. PURPOSE**

The purpose of this standard is to provide a standard laboratory test method for assessing the performance of gas-phase air-cleaning devices. The results of these tests can provide information to the engineer useful for the design and selection of air-cleaning equipment and the design of air-cleaning systems for controlling indoor concentrations of gaseous air contaminants.

## **2. SCOPE**

**2.1** This standard prescribes a full-scale laboratory test method for measuring the performance of in-duct gas-phase air-cleaning devices. This test is conducted under steady-state conditions at elevated gas challenge concentrations (relative to ventilation applications) and, therefore, shall be used to compare devices rather than directly predict performance in any particular application.

**2.2** The method of testing measures the performance of air-cleaning devices for removing one or more specified gaseous contaminants or gas mixtures intended to simulate operation during service life. This standard defines procedures for the dispersion of the gases required for conducting the test. It also provides a method for determining gas concentrations upstream and downstream of the air-cleaning device to calculate removal efficiency.

**2.3** This standard establishes performance specifications for the equipment required to conduct the tests, defines methods of calculating and reporting results obtained from the test data, and establishes a result reporting system that can be applied to the gas-phase air-cleaning devices covered by this standard.

**2.4** The test method defined by this standard is applied to a sample device that is assumed to be representative of other devices marketed with the same brand and model number.

**2.5** This standard does not apply to stand-alone room air cleaners.

### **3. DEFINITIONS, AND ACRONYMS, AND ACCEPTED SAMPLING AND ANALYTICAL METHODS**

#### **3.1 Definitions**

Key terms are defined below for the purposes of this standard. Definitions for adsorbent and challenge compound are taken from ISO 29464 (ISO, 2017). For definitions not provided here, refer either to ASHRAE Terminology <sup>1</sup> or to ASTM's *Standard Terminology Relating to Activated Carbon* <sup>2</sup>. Otherwise, common usage shall apply.

**absorption:** ~~the~~ transport and dissolution of one substance into another to form a mixture having the characteristics of a solution.

**adsorbent:** material having the ability to capture and retain gaseous gases or vapors contaminants on its surface by physical or chemical processes.

**adsorption (physical):** process in which ~~the~~ molecules of a gas or vapor adhere by physical processes (Van der Waals forces) to the surface, both the outer surface and the inner pore surfaces, of a solid substance.

Note: this is a reversible process under specific conditions (~~See desorption~~).

**air cleaner:** ~~device or system for removing contaminants from air in a ventilation system, building, or other enclosed space.~~ device used to remove airborne impurities from air.

Note: in the context of this standard, airborne impurities refers to gaseous compounds ~~an air cleaner is a duct-mounted device with size up to 61 x 61 cm (24 x 24 in) square and used to remove gaseous contaminants.~~

**air filter:** device for separating solid or liquid particles or gaseous compound contaminants from an air stream passing through the device.

**airflow rate:** volume of air flowing through the test duct per unit time.

**airflow conditions:** the temperature, pressure, and relative humidity of the air in the test duct.

**breakthrough:** see *penetration*.

**breakthrough (penetration) curve:** plot of challenge compound penetration versus time for a particular challenge concentration and airflow conditions.

Note: adsorbent air cleaners often have s-shaped breakthrough curves. Non-sorbents may have flat breakthrough curves.

**breakthrough time ( $t_{bx}$ ):** time to reach a specified penetration level.

Note 1: relevant breakthrough times may be defined as penetrations of 5%, 50%, and 95% ( $t_{b5}$ ,  $t_{b50}$ , and  $t_{b95}$ ).

Note 2: breakthrough time is sometimes referred to as breakthrough point.

Note 3: this concept is most often applied to adsorbent-based air cleaners in which the penetration is expected to change over time. Non-adsorbent air cleaners may maintain a constant penetration.

**bypass:** proportion of the challenge air stream that passes around or through an air cleaner without interacting with the air cleaner.

**by-product:** an airborne substance formed in or downstream of an air cleaner as a result of the air-cleaning process.

Note: the by-products CO<sub>2</sub>, O<sub>2</sub>, and H<sub>2</sub>O (the complete oxidation reaction products), will not be measured due to the small potential contribution from reactions compared to the expected background levels.

**by-product production percentage (BPP):** ratio of the sum of the by-product concentrations, ~~expressed in ppb or ppm,~~ produced to the challenge concentration, expressed as a percentage.

Note: ~~this percentage allows immediate comparison to the removal efficiency to assist in assessing the amount of contaminant that was not completely removed.~~ BPP shall be calculated using concentration in  $\mu\text{g}/\text{m}^3$ .

**capacity:** see *removal capacity*.

**capture efficiency:** see *removal efficiency*.

**catalyst:** ~~any~~ substance of which a small amount relative to the reactants notably affects the rate of a chemical reaction without itself being consumed or undergoing a chemical change. Most catalysts accelerate reactions, but a few (negative catalysts, or inhibitors) retard them.

Note: catalysts may become poisoned, fouled, or deactivated during use.

**channeling**: ~~the~~ disproportionate or uneven flow of gas through passages of lower resistance that can occur in fixed beds or columns of granular media.

Note: causes of channeling include non-uniform packing, irregular sizes and shapes of media, gas pockets, and wall effects.

**Challenge compound**: ~~chemical~~ compound that is being used as the airborne chemical contaminant of interest for any given test.

**challenge air stream**: ~~the~~ test compound(s) of interest diluted with clean air to the concentration(s) and airflow conditions of the test.

Note: this is the gas stream that contacts the air cleaner at a defined face velocity to produce a desired residence time.

**chemisorption (chemical adsorption)**: ~~the~~ binding of a compound (gas or vapor) to the surface of a solid by forces with energy levels approximately those of a chemical bond. Binding occurs to both inner and outer pore surfaces. Binding is usually followed by a chemical reaction that removes the compound from the airstream but may add other gases to it.

Note: this is an irreversible process.

**concentration**: ~~the~~ quantity of one substance dispersed in a defined amount of another.

**desorption**: process in which ~~adsorbed~~ captured molecules are released from the adsorbent ~~leave the surface of a physical adsorbent~~ and re-enter the air stream.

Note: desorption is the opposite of adsorption.

**density, apparent (density, bulk)**: mass under specified conditions of a unit volume of a solid physical adsorbent or chemisorbent, including its pore volume and inter-particle voids.

**efficiency**: see *removal efficiency*

**efficiency, initial**: see *removal efficiency, initial*

**efficiency, initial corrected**: see *removal efficiency, initial corrected*

**efficiency curve**: see *removal efficiency curve*

**electronic air cleaner (EAC)**: device or system for removing compound~~contaminants~~ from air by a process that requires use of electrical power supplied to the air-cleaning technology.

Note: examples include photo-catalytic oxidation and nonthermal plasma (bipolar ionization, needled point discharge, barrier discharge, corona discharge).

**end point**: ~~the~~ point at which the test is stopped due to (a) specified elapsed time or (b) reaching the maximum specified concentration of a challenge compound in the air downstream of the air cleaner.

**face velocity:** ~~the~~ velocity of the air at the inlet of the air cleaner.

Note: Duct Velocity = airflow rate/ cross sectional area of the duct (61 x 61 cm [24 x 24 in.]).

**full-scale test:** a test conducted with a full-size production model of the gaseous-~~compound~~~~contaminant~~ air cleaner.

**in-duct air cleaning device:** air cleaner that is designed to be installed in an HVAC duct or that can be adapted to be tested in a duct.

**inlet:** ~~the~~ location immediately before the challenge air stream contacts the air cleaner holding section.

Note: not to be confused with the less specific term “upstream.”

**media:** granular or pelletized physical adsorbents, chemisorbents, or catalytic materials used in air cleaners, or materials containing (supporting) such physical adsorbents, chemisorbents, or catalytic materials.

**mesh size:** ~~the~~ average number of grains or pellets per linear inch (25.4 mm) when referring to media as characterized by standard sieve sizes (see ASTM D 2862 3), or the number of perforations per linear inch (25.4 mm) when referring to screens or plates, often expressed as a range (e.g., 8 to 12 mesh).

**nonthermal plasma (NTP):** air cleaning technology that creates ions and/or reactive oxygen and nitrogen species to react with gaseous compound~~contaminants~~.

Note 1: NTP includes bipolar ionization, needle point discharge, barrier discharge, corona discharge.

Note 2: by-products are formed when gaseous compounds are broken down~~contaminants are removed~~.

**outlet:** ~~the~~ location immediately after the air cleaner holding section.

Note: not to be confused with the less specific term, “downstream.”

**penetration:** ~~the~~ ratio of challenge compound concentration downstream of the air cleaner to the upstream (challenge) concentration, sometimes expressed as a percentage.

Note: related to percent efficiency by the expression, Efficiency =  $(1 - \text{Penetration}) \times 100\%$ .

**photo-catalytic oxidation (PCO):** ~~an~~ air-cleaning process that uses light and a semiconductor catalyst to remove gaseous compound~~contaminants~~ from the challenge air stream via surface-mediated oxidation-reduction (redox) reactions.

Note: by-products are formed when gaseous compounds are broken down~~contaminants are removed~~.

**pressure drop:** see *resistance to airflow*.

**pull sample:** sample of airborne compound~~contaminant~~ (s) obtained by using a pump to draw air into or through a sorbent tube, cartridge, or other capture device.



***reactive oxygen species:*** ~~chemically reactive species containing oxygen.~~ unstable oxygen-containing radicals and non-radical species.

Note: ~~examples include peroxides, superoxide, hydroxyl radical, singlet oxygen, nitric oxide, and nitrogen dioxide.~~ this includes, but is not limited to, superoxide ( $O_2^-$ ), hydroxyl ( $\bullet HO$ ), hydroperoxyl ( $HOO\bullet$ ), alkylperoxides ( $ROO^-$ ), hydrogen peroxide ( $H_2O_2$ ), organic peroxides ( $ROOR$ ), hypochlorite ( $ClO^-$ ), and peroxyxynitrite ( $ONOO^-$ )

***removal capacity:*** total amount (mass or moles) of a challenge compound that can be removed by an air cleaner under given test conditions and end point (termination time).

Note: capacity can be ~~negative~~ decrease during ~~due to desorption in any device where physical adsorption occurs.~~

***removal efficiency:*** fraction or percentage of a challenge compound that is removed from the challenge air stream by an air cleaner.

***removal efficiency, corrected:*** ~~removal efficiency modified to account for the concentration of by-products produced.~~

***removal efficiency, corrected, initial:*** ~~the average corrected efficiency calculated over the 1-hour period of the low concentration test.~~

***removal efficiency, initial:*** ~~the average~~ removal efficiency calculated over the 1-hour period of the low concentration test.

***removal efficiency curve:*** ~~a plot of challenge compound~~ removal efficiency (or mass fraction of challenge compound removed) against test duration time for a particular challenge concentration and airflow conditions.

***residence time (t<sub>r</sub>):*** ~~the theoretical time that an increment of air (or gaseous compound)~~ is within the confines of an air cleaner, ignoring the fraction of internal volume that is occupied by the components of the air cleaner.

***resistance to airflow:*** ~~the~~ difference in absolute (static) pressure between two points in an airflow system.

Note: for the purposes of this standard, the two points are usually (1) at the inlet and outlet of the air cleaner holding section or (2) across the ASME nozzle.

***retentivity:*** measure of the ability of a physical adsorbent or air cleaner to resist desorption of a challenge compound.

Note: the level of retentivity depends on the conditions of the test.

***vapor-phase compound*** ~~contaminant~~ (*vapor*): substance whose vapor pressure is less than the ambient pressure at ambient temperature but is present in the gas phase through evaporation or sublimation.

Note: hydrocarbons that contain five or more carbons are generally vapors.

### 3.2 Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
BPI	Bi-polar Ionization
BPP	By-product Production Percentage
BT	breakthrough
cfm, ft <sup>3</sup> /min	cubic feet per minute
cmh, m <sup>3</sup> /h	cubic meters per hour
GC	gas chromatograph
HEPA	high-efficiency particulate air
HVAC	heating, ventilating, and air-conditioning
Pa, kPa	pascals, kilopascals
PEL	permissible exposure limit
PTFE	polytetrafluoroethylene
RH	relative humidity, %
THC	total hydrocarbon analyzer
UV	ultraviolet light
UV-C	a portion of the UV spectrum from 200-280 nm
UV-PCO	Ultraviolet-Photo Catalytic Oxidation
VOC	volatile organic compounds
316SS	stainless steel alloy designation 316
ppbv	parts per billion by volume
ppmv	parts per million by volume

### 3.3 Accepted VOC, ~~and Aldehyde,~~ and Inorganic Compound Sampling and Analytical Standards

#### 3.3.1 Volatile Organic Compounds

- EPA IP-1. Determination of volatile organic compounds (VOCs) in indoor air, 1990.
- ISO 16000-6. Indoor air - Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS or MS-FID, 2011.
- ISO 16017-1. Indoor, ambient and workplace air - Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography - Part 1: Pumped sampling, 2000.
- ISO 16017-2. Indoor, ambient and workplace air - Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography - Part 2: Diffusive sampling, 2003.
- EPA TO-1. Method for the determination of volatile organic compounds in ambient air using TENAX adsorption and gas chromatography/mass spectrometry (GC/MS), 1984.
- EPA TO-14A. Determination of volatile organic compounds (VOCs) in ambient air using specially prepared canisters with subsequent analysis by gas chromatography, 1999.
- EPA TO-15. Determination of volatile organic compounds (VOCs) in air collected in specially prepared canisters and analyzed by gas chromatography/mass spectrometry (GC/MS), 1999.
- EPA TO-17. Determination of volatile organic compounds in ambient air using active sampling onto sorbent tubes, 1999.
- ASTM D5466-15. Standard test method for determination of volatile organic compounds in atmospheres (canister sampling methodology), 2015.

- ASTM D6196-15e1. Standard practice for choosing sorbents, sampling parameters and thermal desorption analytical conditions for monitoring volatile organic chemicals in air, 2015.

### 3.3.2 Aldehyde Compounds

- EPA IP-6. Determination of formaldehyde and other aldehydes in indoor air, 1990.
- ISO 16000-3. Indoor air - Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air - Active sampling method, 2013.
- EPA TO-5. Method for the determination of aldehydes and ketones in ambient air using high performance liquid chromatography (HPLC), 1984.
- EPA TO-11A. Determination of formaldehyde in ambient air using adsorbent cartridge followed by high performance liquid chromatography (HPLC) [active sampling methodology], 1999.
- ASTM D5197-16. Standard test method for determination of formaldehyde and other carbonyl compounds in air (active sampler methodology), 2016.
- Testing method that is compliant with the California Air Resources Board's (CARB) § 93120, European DIN Standard EN-717, and ASTM methods D-5582 and E-1333

### 3.3.3 Inorganic Compounds

- ASTM D3162-21. Standard test method for carbon monoxide in the atmosphere (continuous measurement by nondispersive infrared spectroscopy), 2021.
- ASTM D3824-20. Standard test methods for continuous measurement of oxides of nitrogen in the ambient or workplace atmosphere by chemiluminescence, 2020.
- ASTM D5149-02 (2016). Standard test method for ozone in the atmosphere: continuous measurement by ethylene chemiluminescence, 2016.
- ASTM D5156-02 (2016). Standard test methods for continuous measurement of ozone in ambient, workplace, and indoor atmospheres (ultraviolet absorption), 2016.
- NIOSH 6015. Ammonia, in the NIOSH Manual of Analytical Methods (NMAM), Fourth edition, 1994.
- NIOSH 7907. Volatile acids by ion chromatography (hydrochloric, nitric, and hydrobromic acids), in the NIOSH Manual of Analytical Methods (NMAM), Fifth edition, 2014.

## 4. TEST APPARATUS

**4.1 Performance Objectives of the Test Apparatus.** The test apparatus described below has broad capability and could be used for a wide range of research, developmental, and standard tests. It could be slightly modified and used in many additional ways. However, when used to perform tests required by this standard, the test apparatus shall have the following specific performance characteristics and objectives:

- a. The capability of accepting, for testing, commercial in-duct air-cleaning devices of between ~~850~~ 170 and 3400 cmh (~~500~~ 100 and 2000 cfm) rated airflow at the rated resistance to airflow of the test devices.
- b. The capability of accepting complete air-cleaning devices up to 61 × 61 cm (24 × 24 in.) square.
- c. Be fitted with a Air-cleaning device holders/mounting fixtures and hardware capable of preventing unintended bypass around the air-cleaning device.
- d. The capability of presenting the test air-cleaning device a uniform challenge airstream at a uniform and well-controlled flow rate, temperature, and humidity. The test airstream must contain the desired ~~test~~ challenge compound uniformly distributed at the desired concentrations and must not

- contain extraneous compound~~contaminant~~s that will affect the measurements. It must maintain these test-operating conditions for the duration of the test.
- e. The capability of providing, upstream and downstream of the tested air-cleaning device, gas samples that are representative of the challenge and penetrating compound~~contaminant~~ and to deliver these samples unaltered to appropriate gaseous compound~~contaminant~~ analyzers and instrumentation to measure device removal efficiency and to demonstrate compliance with these objectives.
  - f. Be fitted with sSeals that are tight and have been tested to meet the requirements of the test organization's occupational health requirements for the test duct operators.
  - g. Be fitted with aAdequate post-challenge gas gaseous compound removal devices to reduce apparatus compound~~contaminant~~ exhaust levels to environmentally acceptable levels.

Section 4 of this standard describes how this standard test method proposes to meet these objectives. Section 5 describes the objective measures that will be used to show that a particular test apparatus meets the objectives of this standard test method.

**4.2 Mandatory and Discretionary Requirements.** The duct dimensions and design provided below largely follow ASHRAE Standard 52.2 <sup>4</sup> and are capable of providing adequate gas mixing and flow development. The mandatory requirements for the duct are specified to ensure upstream and downstream flow development and gas contaminant mixing. Duct construction guidance is provided for the convenience of the user of this method. However, the test method is specified by the validation and quality assurance (QA) requirements, which must be met. The design of equipment not specified, such as blowers, valves, external piping, and instrumentation, is fully discretionary. The equipment shall have adequate capacity to meet the requirements of this standard.

### 4.3 Test Duct

**4.3.1 Overview.** The test duct for this standard is similar to that required for the Standard 52.2 <sup>4</sup> test in size, general construction, and airflow monitoring capability. It differs in challenge compound~~contaminant~~ generation, sampling and analytical instrumentation, precision of the temperature and humidity control, challenge compound~~contaminant~~ removal, and some aspects of the duct-qualification requirements. Switching between the particle filter test of Standard 52.2 and the gaseous compound~~contaminant~~ test described in this standard should be possible, provided that the duct is qualified at each switchover either through new qualification tests or that the switchover is accomplished without changing the duct specifications that meet a given requirement. If the duct is also to be used for Standard 52.2 testing, the requirements that the duct be electrically conductive and electrically grounded must also be met. Additionally, the gas injection/sampling inlets required by this standard, if allowed to remain in place between tests, shall not interfere with the aerosol performance of those for Standard 52.2.

**4.3.2 Duct Design.** A schematic of the test duct is shown in Figure 4-1. It meets all requirements of the Standard 52.2 <sup>4</sup> test and is essentially a square cross section, 61 × 61 cm (24 × 24 in.). An alternate size or shape, such as a circular duct, may be used for testing to this standard if the QA specifications are modified for that shape; this method assumes the Standard 52.2 specifications. The test duct is permitted to be recirculating or once-through, provided that the quality assurance requirements of the method are met. Figure 4-1 shows the availability of access to conditioned room air in the once-through mode and the ability to exhaust to the outdoor air (discharge) after passing through challenge scrubber absorbers. The duct material shall be sufficiently rigid to maintain its shape at the operating pressures and shall have a smooth interior finish to reduce retention of the challenge compound~~contaminant~~s. Stainless steel is recommended but not required. The inlet filter bank must contain high-efficiency particulate air (HEPA) filters in addition to gas-phase air cleaners. Increasing the cross section of the duct at the inlet filter bank to accommodate

more than one 610 × 610 mm (24 × 24 in.) HEPA filter to minimize resistance to airflow is allowed. The inlet filter bank must discharge along the centerline of the upstream mixing orifice.

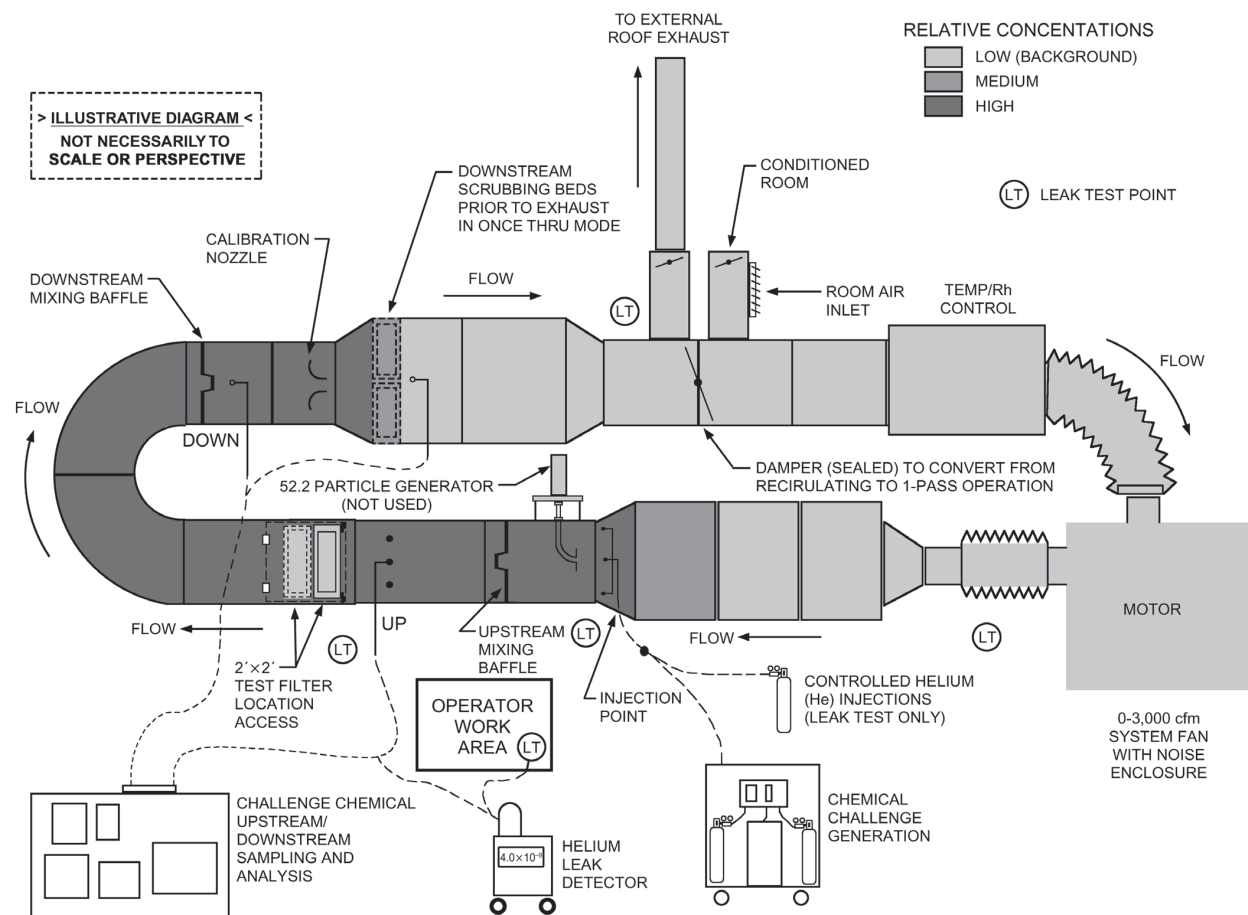
The test method is intended to evaluate complete air-cleaning devices having a nominal cross-section size of up to 61 × 61 cm (24 × 24 in.) at flow rates between 850 and 3400 cmh (500 to 2000 cfm). As is true of the Standard 52.2 test, the required fan capacity is a function of maximum flow rate and maximum total resistance to airflow. The major resistance to airflows in the flow system are caused by the test air-cleaning device, the gas mixing apparatus, the flow measurement nozzle, the inlet and outlet gas cleaning devices, and the various expansions and flanges inherent in the test duct. The test duct pressure-drop capability (duct construction, sealing, and fan selection) should be evaluated based on expected total requirements.

Table 4-1 references the applicable figures in Standard 52.2 that provide details of the required test apparatus.

**4.3.3 Configuration.** The recirculating configuration of the duct, as shown in Figure 4-1, is optional. Either a straight or a U-shaped duct shall be permitted. If a U-shaped duct is used, the curved portion may be beside, above, or below the main test run. Except for the bend itself, all dimensions, and components (including the downstream mixing orifice and baffle) are required to be the same for the straight and U-shaped configurations.

**4.3.4 Air Source.** Room air, recirculated air, or a mixture shall be used as the test air source. The mean temperature and RH of the air at the test air cleaner shall be controlled to the test parameter values specified in Section 6.1. Exhaust flow shall be discharged outdoors, indoors, or recirculated; adequate precautions must be taken to ensure safety and acceptable discharge limits for each case. Note that the temperature and RH for flow measurement and control (Section 4.4) are not necessarily the same as the device temperature and RH.

**4.3.5 Duct Mixing Components.** A mixing component (e.g., an orifice plate and mixing baffle) shall be located ~~downstream of~~ between the contaminant challenge compound injection point and the air cleaning device. An identical mixing component shall be located downstream of the ~~test~~ air cleaning device. Details for these components are provided in Standard 52.2 <sup>4</sup> in the locations shown in Table 4-1.



**NOTES for Figure 4-1:**

1. From one duct diameter upstream of the upstream mixing baffle through two duct diameters downstream of the ASME calibration nozzle, the duct segments shall have a cross section of 61 × 61 cm (24 × 24 in.), excluding the device section.
2. The upstream duct components shall be in centerline alignment from the fan transition through the test air cleaner and shall extend 3 duct diameters downstream of the trailing edge of the test air cleaner cartridge.
3. The downstream duct components shall be in centerline alignment from the downstream mixer through two duct diameters downstream of the ASME flow nozzle.
4. Upstream airflow and gas concentration traverse measurements required in Section 5 shall be performed at the upstream sample point (UP).
5. Gaseous challenge compound contaminant injection shall occur as shown, downstream of the inlet clean up filter bank, and shall be capable of meeting the requirements of Section 4.5.
6. Side-by-side, over-and-under, and once-through arrangements of the upstream and downstream sections of the test duct shall be permitted.

**FIGURE 4-1 ASHRAE Standard 145.2 test duct schematic.**

**TABLE 4-1 ASHRAE Standard 52.2 Figure References**

Item	Description	ASHRAE Standard 52.2 Figure
1	Mixing orifice detail	4-2a
2	Perforated plate detail	4-2c
3	Static tap detail	4-2b
4	Static tap location	4-2d
5	Reducing transition ducting	4-3a
6	Enlarging transition ducting	4-3b
7	Nonrigid duct section	4-3c

**4.3.6 Challenge Compound Contaminant Injection Location.** The gaseous challenge ~~contaminant~~ compound shall be injected into the duct between the inlet filter bank and the upstream mixing orifice. The gaseous challenge compound ~~contaminant~~ injection system shall produce an upstream challenge that meets the requirements of Section 4.5 and the various qualification criteria in Section 5.

**4.3.7 Vibration Isolation.** The test duct containing the filter under test shall be isolated from vibration caused by the blower or other vibration sources, preferably by using a non-rigid duct section.

**4.3.8 Test Device Size.** The test apparatus shown in Figure 4-1 is designed for test devices with nominal face dimensions of up to 61 × 61 cm (24 × 24 in.) or intended for operation in this cross section. Smooth transitions in accordance with Standard 52.2<sup>4</sup> Figures 4-3a and 4-3b are recommended for test devices with face areas differing from the normal test duct cross-section area of 0.37 m<sup>2</sup> (4 ft<sup>2</sup>). It shall be permitted to test specially sized air cleaners if the size requirement cannot otherwise be met. The section of the duct where the air cleaner is installed shall be the appropriate size for the air cleaner for the whole distance needed for that device type as specified by the manufacturer.

**4.3.9 Challenge Compound Contaminant Recycle.** To avoid challenge concentration drift, it is recommended that the duct ~~challenge compound~~ contaminant generation system be responsible for 99% or more of the inlet ~~challenge compound~~ contaminant loading for the complete duration of the test, as demonstrated by measurements in either the recirculate or once-through modes. In the once-through mode, the inlet room air must be ~~challenge compound~~ contaminant free, or be cleaned such that it is nearly ~~challenge compound~~ contaminant free. “Compound Contaminant” in this context means any ~~compound~~ contaminant that could interact with the device being tested, not just the intended test ~~challenge compound~~ contaminant. In the recirculate mode, the combination of inlet and recirculation gaseous air cleaners shall have adequate capacity to meet this requirement from the beginning of ~~challenge compound~~ contaminant injection until the tested air cleaner reaches the desired penetration endpoint and the desorption check is complete. In either case, the gaseous air cleaners shall be followed by appropriate particulate prefilters and high-efficiency filters to prevent contaminated clean-up particles (adsorbent or otherwise) from being entrained and carried into the testing zone. Increasing the cross section of the duct at the inlet and clean-up filter banks to accommodate air-cleaners or filters in parallel is suggested. The inlet filter bank must discharge along the centerline of the upstream mixing orifice.

**4.4 Duct Flow Measurement.** The duct airflow measurement shall be made by means of an appropriately sized ASME long-radius flow nozzle (see Standard 52.2<sup>4</sup>, Figure 9-1) with static taps (see Standard 52.2, Figure 4-2b) located downstream of the downstream sample tap (see Standard 52.2, Figure 4-2d). The temperature, absolute pressure, and RH of the test airflow shall be measured in the duct immediately upstream of the flow-measuring orifice. These values shall be used for calculation of airflow rate.

## **4.5 Gaseous Challenge ~~Contaminant~~ Compound Generation**

**4.5.1 Challenge ~~Contaminant~~ Compound Overview.** The gaseous challenge ~~contaminants~~ compounds shall be specified by the user consistent with requirements of this method as stated in Section 6, “Test Conditions and Materials.” Other than the requirements of the following subsections, the design features of the gaseous ~~challenge compound~~ contaminant generator are left to the discretion of the equipment manufacturer.

Challenge compounds ~~Contaminants~~ that are gases at the test conditions can be conveniently metered and injected through a manifold and mixed within the test duct. The ~~gase~~ contaminant-mixing capability of a Standard 52.2<sup>4</sup> test rig is adequate. If the challenge chemical is a pure compressed gas, the flow rate required

may be too low to pressurize the entire injection manifold. In such a case, injection into a carrier gas (clean air or inert gas) and subsequent injection into the test duct is recommended. If the challenge chemical is delivered as a pressurized mixture, direct injection may be possible. In all cases, the test operator must be alert to issues such as condensation due to expansive cooling, particularly if a mixed chemical challenge is being used. Heat tracing may be required.

The generation of gaseous challenges from liquid chemicals is less straightforward. While some high-volatility chemicals could be sprayed into the duct and vaporized from the aerosol state, this technique will not be satisfactory for all liquids. Unvaporized aerosol particles that reach a granular bed of sorbent have a high probability of penetrating the control device. They may then vaporize downstream, be sampled, and confound the results. For this reason, the recommended test method is that 100% of the challenge liquid be vaporized into a carrier gas prior to injecting the challenge compound~~contaminant~~ into the duct, which requires the test operator to ensure that at least 95% of the challenge mass is vaporized before the challenge reaches the air-cleaning device. This vaporization must be accomplished safely with appropriate regard for explosive and flammable limits. For more information on safety see Section 12.2.2.

**4.5.2 Challenge ~~Contaminant~~ Compound Concentration Consistency.** The gaseous challenge compound~~contaminant~~ generators shall be designed to ensure that the ~~contaminant~~-challenge remains within  $\pm 10\%$  of the mean for the equally time-spaced measurements taken throughout the duration of the test. The maximum concentration deviation from the mean shall be no more than 20% of the mean. The results of the test shall be reported at the actual mean test concentration, not at the target concentration.

**4.5.3 Challenge Generator Flow Rate.** If possible, the maximum flow rate of the challenge compound~~contaminant~~ generator stream should be less than 1% of the total test flow rate (e.g., 34 cmh [20 cfm] carrier gas or less for a 3400 cmh [2000 cfm] test flow) to maximize the flow passing through the environmental control system. This maximum flow rate is generally acceptable for chemicals having vapor pressures at or above toluene, for example, at concentrations in the range of 100 ppm. For some high-boiling chemicals at higher challenge concentrations and/or lower total flow rates, higher generator flow rates may be required.

## 4.6 Gas Sampling

**4.6.1 Gas Sampling Overview.** Gas sample transport through PTFE and 316SS sample lines is normally very efficient. PTFE is preferred when sampling for ozone. When the air-cleaning device efficiency changes slowly relative to the sample processing rate, sample line length is often not a major issue, although it must be checked when new challenge chemicals are utilized. For tests where the efficiency changes rapidly, the timing for the sample lines shall be taken into account in the data analysis. Tests with the standard test chemicals can usually be conducted using the same real-time analyzer(s) upstream and downstream, if the concentrations are appropriate for the analyzer. Pull samples will require separate sets of samplers and pumps for upstream and downstream. For the pull samples, the data analysis shall use the mean time of the sample. For example, a 20-minute sample starting at  $t=10$  min would be considered as data for time  $t=20$  with adjustment for time to get the sample from the rig to the sampler.

Separate upstream and downstream sample and analysis systems for real-time measurements may be preferred in some cases to provide additional detail in the data or to simplify the test procedure. For instance, a device having low capacity at the test concentration may change performance so quickly that sequential upstream and downstream sampling using only one analyzer for a specific compound is not sufficiently frequent to characterize its efficiency. A similar situation could arise if a sample analysis procedure that is slow, relative to the change in device performance during the test, was required for the test



compoundcontaminant chosen (e.g., a GC with a relatively long analysis cycle). Another case that might indicate separate upstream and downstream sampling and analysis would be the measurement of very high-efficiency devices for which the upstream and downstream concentrations are so different that the same analyzer cannot be used to determine the efficiency at the levels that may be requested. Dual-analyzer systems do not require purging between samples as long as sampling ensures that the sample rate or sampling flow rate purges the lines to allow only the current sample to be analyzed. Otherwise, the procedures are the same: the data quality requirements for single-analyzer and dual-analyzer systems are identical.

For pull samples, this discussion is relevant in that the samples for upstream and downstream could be simultaneous or sequential. For the initial efficiency test, the upstream and downstream samples shall be simultaneous as much as possible. At least triplicate samples for both aldehydes and VOCs shall be taken to cover at least 45 minutes of the hour of the initial efficiency test. If pull samples are used during the capacity test, sequential testing is allowed.

In addition to the main challenge compoundcontaminant, all air cleaners will be tested for production of ozone and other possible reaction by-products. This will require sampling upstream and downstream of the devices for both the test with the air cleaner and the no device correlation test. During the initial efficiency test when using a VOC challenge compound, sampling for at least two aldehydes and three VOCs will be required for any challenge contaminant-compound that could produce them. By-product molecules are usually smaller than the challenge compound and contain more oxygen. For example, by-products of hydrocarbon breakdown include ketones, aldehydes, and alcohols.

Other than the requirements of the following subsections, the design features of the sampling system are discretionary.

**4.6.2 Sampling System Design Criteria.** The design criterion for the sampling systems used with real-time analyzers shall be to provide, at 1% of the challenge concentration, transport of  $\geq 95\%$  of the challenge compoundtest-contaminant(s) from both the upstream and downstream sample probe inlets within the test duct to the inlet of the gas analyzers. Transfer tubes and connectors of smooth-walled 316SS and/or PTFE are generally suitable and exhibit acceptable losses. If possible, the residence time in the total length of the sampling tube should be less than 1 s. If residence time is greater than 30 s or half of the analyzer sample time for any analyzer, the operator shall determine the sample transport time and account for sampling time lag. Because gas analyzers generally have low sampling rates, auxiliary pumps may be required to move sampled gas more rapidly to the analyzers. In this case, the capability of the analyzers to sample from below atmospheric pressure shall be considered in the sampling system design. Flow through the sampling system to the vicinity of the analyzers shall be measured with a precision of 5% of the sample rate. The airflow rate of the upstream and downstream sampling systems shall be as low as possible, consistent with the transport requirements of this section, and not greater than 2% of the test air-flow rate. If an auxiliary pump is required, the pump and associated flow control and flow measurement devices of the primary sampling lines should be downstream of secondary probes whenever possible. If this is not possible, it shall be demonstrated that they do not contribute compounds of interestcontaminants, and they shall be considered in the sample loss evaluation.

Pull samples shall meet the same time-for-transport requirements. It is expected that individual sampling pumps would be used for each sample, but the requirement is simply to follow the requirements for the specific gas collection devices in use.

Sampling for ozone and other by-products may be done through the same sampling lines as the challenge gas compound if the flow can be split between the samples and PTFE sample lines are used. This can be done by using a pump to pull air from the duct to a plenum from which all analyzers pull separate samples. The plenum should not be shared between upstream and downstream. Alternatively, separate sample lines for each analyzer may be run.

**4.6.3 Duct Mixing.** The duct mixing requirements are intended to fully mix the challenge and penetrating gas. However, if mixing is unlikely to be adequate (e.g., for an air cleaner with known nonuniform bypass), the use of multi- point sampling manifolds is recommended. The manifolds should be designed to sample equally from six or more equal- area portions of the duct cross section.

**4.6.4 Validation of Transport Loss Rate.** Whatever sampling rate and tube materials are used, transport losses shall be verified to meet the design requirements by experimental measurement in all cases. Heat tracing may be required for vapor transport to minimize surface losses or to inhibit moisture condensation. This validation must be done for challenge gases compounds and likely by-products or the class of by-products.

**4.7 Gas Analyzers.** The gas analyzers (or analysis method) that are selected are required to be appropriate for the test challenge compound~~contaminants~~. The analyzers shall have detection limits that are less than the minimum concentration needed to be measured (typically 1% of challenge concentration. If the challenge concentration is less than 100 ppb, this percentage may need to increase because measuring concentrations below 1 ppb is currently difficult) and not be subject to interference from other chemicals in the test challenge. The instrument must have adequate response time (< 2 minutes), accuracy (± 5%), and precision (± 5%), and be stable for the expected test duration. The response of the instrument is most easily analyzed if it is linear, but modest nonlinearity is acceptable, provided that sufficient calibration is done.

Different analyzers using different analytical techniques may be required for different challenge compound~~contaminants~~. New analyzers are frequently developed, but developments in equipment design cannot be anticipated. The testing organization is responsible for ensuring that the analyzer is appropriate for the challenge compound~~contaminant~~ and concentration being utilized and that no interference is confounding the test.

**4.8 Sampling/Collection Devices and Analysis.** Sampling devices and sampling volumes must be chosen in conjunction with analysis technique to meet acceptable detection limits for each required compound and used to limit or eliminate interference. For example, ozone removal cartridges may be needed for some sampling tubes. Samples that are not analyzed in real time shall be stored and analyzed per the sampling techniques requirements. Samples should be taken in triplicate at the same time if possible. Sampling sequentially with many samples to define a curve is acceptable. Overlapping samples are also acceptable as long as there is sufficient data to define a curve and to have the data set remain usable if 1-2 samples appear to be outliers.

For all tests with carbon containing challenge compounds except CO<sub>2</sub> (VOCs, aldehydes), where by-products are measured, aldehyde samples shall be taken using one of the techniques cited in Section 3.3 with analysis for expected aldehydes based on the challenge. In all cases, formaldehyde and acetaldehyde shall be included in the analyte list. In addition to the aldehydes, VOC samples using one of the Section 3.3 methods shall be taken and analyzed for any challenges containing carbon except for CO<sub>2</sub>. Compounds to be included in the analysis should be based on the challenge compound but shall include at least acetone

and formic acid. For challenges containing sulfur, sulfur oxides shall be included as by-products. For challenges containing including chlorine, phosgene shall be included.

A table of by-products that shall be monitored is given in Table 4-2

**Table 4-2 By-products.**

<u>Compound</u>	<u>Challenge Gas</u>	<u>Concentration Limit*</u>	
		<u>µg/m<sup>3</sup></u>	<u>ppb</u>
<u>Formaldehyde</u>	<u>All</u>	<u>2</u>	<u>1.6</u>
<u>Acetaldehyde</u>	<u>All</u>	<u>2</u>	<u>1.1</u>
<u>Ozone (O<sub>3</sub>)</u>	<u>All</u>	<u>10</u>	<u>5</u>
<u>VOCs (individual)</u>	<u>All</u>	<u>5</u>	<u>N/A</u>
<u>Nitrogen Oxides (NO, NO<sub>2</sub>)</u>	<u>All</u>	<u>10</u>	<u>N/A</u>
<u>Sulfur Oxides (SO, SO<sub>2</sub>)</u>	<u>Sulfur containing compounds</u>	<u>10</u>	<u>N/A</u>
<u>Phosgene</u>	<u>Chlorine containing compounds</u>	<u>10</u>	<u>2.5</u>

\*Concentration limit shall determine when by-products shall be reported if they exceed the concentration.

**4.9 Full-Scale Apparatus Leak Potential.** The large-scale apparatus used for air-cleaner challenge testing with toxic gases shall have minimal leakage rates that do not produce excessive work area exposure levels for the operators. The 1% leakage rates allowable for Standard 52.2 <sup>4</sup> testing may not be sufficiently small to limit the work-area concentrations, and additional sealing measures may be required. Section ~~5.3~~ 5.5 defines this additional leak characterization testing.

**4.9.1 Applicable to Full Apparatus.** The full apparatus (not just the test section) should initially be leak sealed to minimize any potential leakage into the operator work area. This sealing will require a concerted effort using gasketing and conformal sealants to seal door openings, section flanges, damper shafts, test point penetrations, etc. Special attention should be paid to all surfaces contacted by contaminated gas between the injection point and the roof exhaust location. All sealing materials should be selected to have minimal out-gassing properties that might subsequently confound testing.

**4.9.2 Conversion from ASHRAE Standard 52.2 Use.** If the apparatus is being converted from Standard 52.2 <sup>4</sup> testing to air-cleaner testing, all unused test probes and openings should be capped or sealed prior to system leak characterization.

**TABLE 5-1 Duct and Instrument Qualification Requirements**

<u>Section Number</u>	<u>Parameter</u>	<u>Specific to Compound Contaminant</u>	<u>Requirement</u>
<u>5.2</u>	<u>Test duct leakage: Ratio of leak rate to test airflow rate</u>	<u>No</u>	<u>&lt; 1.0%</u>
<u>5.3<del>2</del></u>	<u>Background Particle Check</u>	<u>No</u>	<u>Concentration &lt; 3500 particles/m<sup>3</sup> (100 particles/cf).</u>
<u>5.4<del>3</del></u>	<u>Test duct velocity uniformity: Based on traverse measurements made over a 9-point equal-area grid at each test airflow rate (see Figure 5-1).</u>	<u>No</u>	<u>CV<sup>a</sup> &lt; 10%</u>

5.4	Test duct leakage: Ratio of leak rate to test airflow rate	No	<1.0%
5.5	Test duct leakage: Total allowable leakage	Yes	Work-area concentration not to exceed safe limit for the <u>compoundcontaminant</u> used
5.6	<u>Challenge compoundContaminant</u> dispersal uniformity based on traverse measurements made over a 9-point equal-area grid at each test airflow rate and for each unique <u>challenge compoundcontaminant</u> injection manifold design and operating condition (made with either helium or with one of the gaseous <u>challenge compoundsecontaminants</u> )	No	CV < 15%
5.7	Downstream mixing: Based on a 9-point perimeter injection grid and center-of-duct downstream sampling	No	CV < 10%
5.8	<u>Gas Challenge compoundcontaminant</u> generation system maximum flow rate	May vary, but generally specific to the generation system	Limit to 1% of total test duct flow if possible
5.9	Gas analyzer calibration: Zero, or check zero as appropriate to the analyzer, and calibration at approximately 10%, 50%, and 100% of challenge concentration	Yes	Use traceable gas standards Must be done for all analyzers <u>Curve fit <math>R^2 \geq 0.95</math></u>
5.11	<u>Challenge compoundContaminant</u> generator and duct response time	Yes	No predetermined level
5.12	100% efficiency and purge time determination	Yes	>99% efficiency; no predetermined purge time
5.13	No air cleaner test and overall system check	Yes	Calculated efficiency for no air cleaner test <5%; calculated conc. within 10% of measured
5.14	Gas analyzers and sampling systems zeroes	Yes	Below detection limit
5.15	Test air temperature	No	Control to within 2°C; setpoint within 95% CI <sup>b</sup> of mean
5.16	Test air RH	No	Control to within 10% rh; setpoint within 95% CI of mean RH

a. CV = coefficient of variation computed as the standard deviation/mean.

b. CI = confidence interval defined as a range of values so defined that there is a specified probability that the value of a parameter lies within it.

## 5. APPARATUS QUALIFICATION TESTING

**5.1** Apparatus qualification tests shall verify quantitatively that the test rig and sampling procedures are capable of providing reliable challenge compoundcontaminant concentration and air-cleaner removal efficiency measurements. Qualification tests shall be performed as required by Table 5-1. System qualification maintenance requirements are specified in Table 5-2. Though the duct qualification tests performed for Standard 52.2<sup>4</sup> are at slightly different airflow rates than those specified for this standard, these tests are not required to be repeated if no changes were made to the rig that would invalidate the QA tests and the tests are up to date.

**5.2 Test Section Duct Leakage Test.** Air leakage from the test duct shall not exceed 1% of the total airflow rate through the test duct. However, safe operation of the test duct may require a substantially lower leakage

rate, depending on the challenge compound and workspace ventilation rate. The test shall be the same as that required by Standard 52.2<sup>4</sup>. A valid qualification of the test section ducting under Standard 52.2 is permitted to be taken as valid for this test, provided that the test section of the duct was not physically modified to convert to gaseous compound testing.

**5.2.1 Maximum Duct Test Pressure.** The highest test pressure anticipated by this standard is 1500 Pa (5 in. of water)\*.

(footnote)\* This pressure level is significantly below that allowed by Standard 52.2 but is considered prudent for the gaseous compound test, given that leak rates increase more than linearly with duct pressure. The lower duct pressure is designed to provide an additional level of workplace safety. The user should exercise caution and limit pressurization of the duct beyond this level.

**5.2.2 Likely Duct Pressures.** Before running the leak test, operate the test rig as usual. Establish airflow at 850, 1700, and 3400 cmh (500, 1000, and 2000 cfm). Record the actual pressure in the test rig near the filter section for each airflow rate (the gauge pressure relative to the room can be used). If you plan to run at a higher airflow, establish that level and record the rig pressure. Add 250 Pa (1 in. of water) to each pressure number to give an estimate of air pressure in the test rig with an air cleaner in place. Add the 5 in. maximum value from 5.2.1 to this table of values. Turn off the test rig.

**5.2.3 Static Leak Test\*\*.** Seal the test duct immediately upstream of the challenge compound injection location and immediately upstream of the exhaust filter bank by bolting a gasketed solid plate to the duct opening or by other appropriate means. Carefully meter compressed air into the test duct at a low constant rate until the pressure in the rig is stable. Record the metered airflow rate (the leak rate) and the test rig pressure. If the rig pressure is 5 in. or higher, reduce the airflow. If the rig pressure is lower than 5 in. either reduce or increase the airflow to reach a different rig pressure. Allow the rig pressure to stabilize and record the values. Perform this test at three or more airflow rates to develop an airflow vs. rig pressure curve (or line). Alternatively, adjust the airflow rates to give exactly the values from the table created in 5.2.2. However, this is likely to take much longer and will give the same basic data set.

(footnote)\*\* The static leak rate of the test section ducting shall be evaluated by a method similar to that delineated in ANSI/ASME Standard N510<sup>5</sup>.

**5.2.4 Assess Leak Rates.** Use this relationship in conjunction with the table developed in 5.2.2 to determine what the leak rate is for your rig at the pressure corresponding to each airflow rate. If these values are less than 1% of the corresponding flowrates, you have met the criteria for this test.

**5.2.5 Audible Leaks.** At any point in the test, if you hear hissing or otherwise suspect a leak, locate and seal the leak. Start Section 5.2.3 over.

Informative Appendix G provides an example of this test.

**5.32 Background Particle Count Check.** To determine whether the HEPA filters are properly installed and providing adequate particle cleanup, operate the test rig at 3400 cmh (2000 cfm). Using an optical particle counter meeting the specifications of Standard 52.2, measure a series of at least 3 samples downstream of the HEPA filters. Verify that the rig concentration is less than 3500 particles/m<sup>3</sup> (100 particles/cf).

**5.43 Test Duct Velocity Uniformity**

**5.43.1 Velocity Traverse Points.** The uniformity of the challenge air velocity across the duct cross section shall be determined by a 9-point traverse (at the locations shown in Figure 5-1) in the 61 × 61 cm (24 × 24 in.) duct immediately upstream of the air cleaner test section. The uniformity test shall be performed at airflow rates of approximately 850 and 3400 cmh (500 and 2000 cfm), which corresponds to velocities of 0.634 and 2.54 m/s (125 and 500 ft/min), respectively. The velocity measurements shall be made with an instrument having an accuracy of at least 10% of the expected velocity with a resolution of 0.05 m/s (10 ft/min) or better.

**TABLE 5-2 Qualification Maintenance Items and Schedule**

Maintenance Item (Subsection Reference)	Each Test	Each Day	On Challenge Compound Contaminant Change	Biannually or After Duct Modification	Other
<del>Test section leakage (Section 5.2)</del>					
Background Particle Check (Section 5.32)					
Test duct velocity uniformity (Section 5.43)					
<del>Test section leakage (Section 5.4)</del>					
System leak characterization (see Appendix B)				Note 1	
<del>Challenge compoundContaminant dispersal (Section 5.6)</del>					
Downstream mixing (Section 5.7)					
<del>Challenge compoundGas contaminant generation system maximum flow rate (Section 5.8)</del>					
Gas analyzers calibration checks at zero, 10%, 50%, and 100% (Section 5.9)					Every 2 weeks
Gas analyzers zero and span (Section 5.9)					Note 1
Rig Background Check (Section 5.10)					
<del>Challenge compoundContaminant generator and duct response (Section 5.11)</del>					
100% efficiency test (Section 5.12)					Once every 6 months
Purge time (Section 5.12)					Once per year
No-air cleaner test and overall system check (Section 5.13)					At most once per day
Analyzer and sampling system zero (Section 5.14)					
Temperature (Section 5.15)					
Relative humidity (Section 5.16)					
Resistance to airflow across empty test section (Section 5.19)					
Flow rates, resistance to airflows, etc.		Note 2			Note 3
Cleaning of test duct and components					Note 4
Pull sample pump airflow	Note 5				

Notes:

1. In addition to the every-two-year QA check and testing after rig modification, this should be performed before any test with a ~~challenge compound~~ ~~contaminant~~ at a concentration that exceeds safety limits.
2. Monthly visual inspection for proper installation and operation.
3. In accordance with manufacturer's recommendations but at least annually.
4. Cleaning intervals of the test duct, ~~challenge compound~~ ~~contaminant~~ generator systems, sampling lines, and other test components is discretionary.
5. Calibrate at least as often as manufacturer's recommendation.

**5.43.2 Velocity Traverse Requirements.** A 1-minute average velocity shall be recorded at each grid point. The average shall be based on at least 10 readings taken at equal intervals during the 1-minute period. The traverse shall then be repeated two more times to provide triplicate 1-minute averages at each point for the given airflow rate. At each point, the average of the triplicate readings shall be computed.

**5.43.3 Required Uniformity.** The coefficient of variation ([CV] computed as the standard deviation/mean) of the 9 corresponding grid-point air velocity values shall be less than 10% at each airflow rate.

~~**5.4 Test Section Duct Leakage Test.** Air leakage from the test duct shall not exceed 1% of the total airflow rate through the test duct. However, safe operation of the test duct may require a substantially lower leakage rate, depending on the contaminant and workspace ventilation rate. The test shall be the same as that required by Standard 52.2<sup>4</sup>. A valid qualification of the test section ducting under Standard 52.2 is permitted to be taken as valid for this test, provided that the test section of the duct was not physically modified to convert to gaseous contaminant testing.~~

~~**5.4.1 Duct Leakage Test Pressures.** The duct pressures for the leak test are normally the duct operating pressures plus 250 Pa (1 in. of water) at operating conditions of 850, 1700, and 3400 cmh (500, 1000, and 2000 cfm). Duct operating pressures are determined by measuring, without a test device installed, the pressures at the contaminant injection point. When the test operator knows that a very high pressure drop device will be tested, more than 250 Pa (1 in. of water) should be added to the duct operating pressure to account for the higher pressure required.~~

~~**5.4.2 Static Leak Test.** The static leak rate of the test section ducting shall be evaluated by a method similar to that delineated in ANSI/ASME Standard N510<sup>5</sup>. The test duct shall be sealed immediately upstream of the contaminant injection location and immediately upstream of the exhaust filter bank by bolting a gasketed solid plate to the duct opening or by other appropriate means. Compressed air is carefully metered into the test duct until the lowest test pressure is achieved. The airflow rate required to maintain constant pressure is measured and recorded as the leak rate. The test is then repeated for the other two test pressures. The measured leak rates must not exceed 1.0% of the corresponding test airflow rate, and workplace safety considerations may require an even lower leak rate.~~

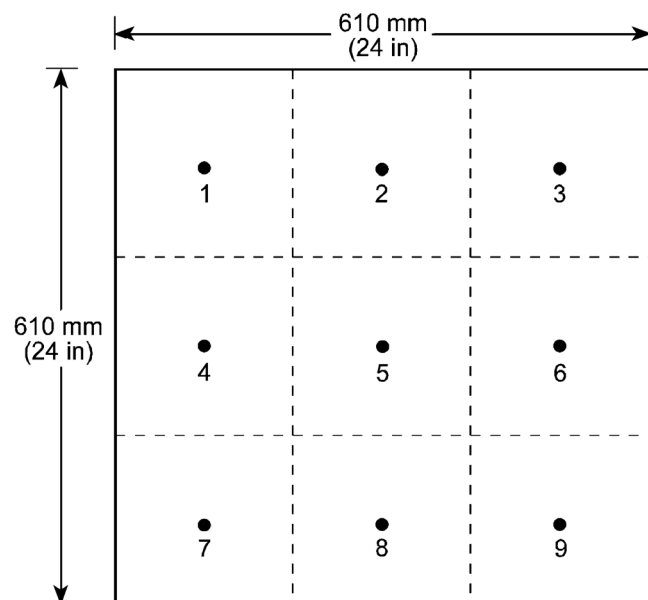


FIGURE 5-1 In-duct velocity traverse points.

**5.4.3 Maximum Duct Test Pressure.** The highest test pressure anticipated by this standard is 1500 Pa (5 in. of water). This pressure level is significantly below that allowed by Standard 52.2<sup>4</sup> but is considered prudent for the gaseous contaminant test, given that leak rates increase more than linearly with duct pressure. The lower duct pressure is designed to provide an additional level of workplace safety. The user should exercise caution and limit pressurization of the duct beyond this level.

**5.5 Full Test Duct Leakage Evaluation and Workspace Tracer Gas Contaminant Measurement.** This test evaluates the leakage into the workspace from the entire test duct operating at 3400 cmh (2000 cfm) in the once-through operating mode. A nontoxic tracer gas shall be used to estimate the potential exposure levels in the operator work area. Additional detail regarding duct leak assessment and the use of the data is provided in Appendix A.

In addition to the test section leak test described in Section 5.2, additional qualification tests are used to control and evaluate full test duct leakage and the resulting workspace contamination. This section describes a manner of determining and minimizing leaks and of estimating challenge compound contaminant concentration in the workspace. PELs provide guidance as to what might be acceptable workspace concentrations, but the allowable exposure limits for a given test laboratory must be set by that laboratory's occupational health policy and requirements. The full test duct leakage test is not required if it can be demonstrated that the air-cleaner contaminant removal test will not result in unacceptable in-room concentrations, such as when the concentration in the rig would be acceptable for breathing.

**5.5.1 Applicable to Full Apparatus.** The full apparatus (not just the test section) should initially be leak sealed to minimize any potential leakage into the operator work area. This sealing will require a concerted effort using gasketing and conformal sealants to seal door openings, section flanges, damper shafts, test point penetrations, etc. Special attention should be paid to all surfaces contacted by contaminated gas between the injection point and the roof exhaust location. All sealing materials should be selected to have minimal out-gassing properties that might subsequently confound testing.



~~**5.5.2 Conversion from ASHRAE Standard 52.2 Use.** If the apparatus is being converted from Standard 52.2<sup>4</sup> testing to air cleaner testing, all unused test probes and openings should be capped or sealed prior to system leak characterization.~~

**5.5.13 Test Pressure Level.** To provide a margin of safety to the leak characterization, the test section shall be pressurized to a level that is twice that required by the actual device test using a suitably sized perforated plate inserted at the test device location. For example, the full duct leak test for a 250 Pa (1 in. of water) resistance to airflow device shall be conducted with a 500 Pa (2 in. of water) resistance plate. The maximum safe working pressure for the test apparatus shall not be reached or exceeded in any case.

**5.5.24 Tracer Gas Injection.** After allowing the flowrate and air temperature to reach equilibrium, a suitable nontoxic tracer gas is injected at the normal challenge injection location. Helium and sulfur hexafluoride are good candidate tracer gases, but any nontoxic gas for which rapid (preferably real time) and low-detection-level analysis is available may be used. The normal laboratory ventilation conditions (air exchange rate) should be used for the test, and the tracer background concentration, if any, shall be determined prior to beginning the leak test. An in-duct tracer challenge concentration level shall be selected that allows the resultant operator work area concentration from the system leakage into the room to be measured using a suitable tracer gas analyzer. The tracer concentration used is selected for test convenience and has no relationship to the planned challenge concentration.

**5.5.35 Scanning for Leaks.** Scans of duct flanges and access doors to identify any major leaks is a good first step in the evaluation. Once the duct is considered to be operating correctly, the tracer concentration in a representative operator work-area locations is monitored until it reaches an equilibrium value. The time required to reach equilibrium depends on duct and laboratory characteristics. Dividing the tracer workspace equilibrium concentration by the in-duct concentration provides a reduction ratio that, for purposes of this test, is considered to be independent of gas compound~~contaminant~~. Reduction ratios on the order of 0.0001:1 have been achieved with a tight duct in a laboratory with 8 air exchanges per hour.

**5.5.46 Estimation of Work Area Concentration.** This reduction ratio is then applied to the planned test concentration for the challenge gas compound to estimate the expected work area concentration level during testing. These computed concentrations are then compared to the allowable workspace concentrations to determine whether the expected level is acceptable.

**5.5.57 Evaluation.** If the operator work-area concentrations levels are not expected to adequately meet the target levels for operator safety, the testing should be terminated, and further leak-point identification and sealing should be conducted. Then the characterization testing shall be repeated.

**5.5.68 Frequency.** Full- or partial-leak characterization testing is recommended whenever the integrity of the test duct has been breached. For example, if a single-access door has been opened in a duct known to have had an acceptable leak rate, the scanning of this door alone may be sufficient. Although frequent characterization may not be necessary with low toxicity challenges, it may be required for others. Operator safety is the responsibility of the test organization.

**5.5.79 Estimation of Air Exchange Rate.** Monitoring the rate of reduction in tracer gas concentration in the operator work area upon cessation of the tracer challenge injection each time the leak characterization test is conducted allows a determination of the effective air exchange rate of the laboratory. Comparison of the air exchange rate with the characteristics of the room ventilation system, plus air-exchange-rate influencing factors such as door/window opening status, allows any unexpected effects of area ventilation to be monitored.

## 5.6 Challenge Compound~~Contaminant~~ Dispersal in the Test Duct

**5.6.1 Overview.** Gas ~~contaminant~~ compound spatial dispersal uniformity is established by generating a test ~~contaminant~~ compound and measuring the concentration at multiple points in the test section. The test ~~contaminant~~ compound and generation system are chosen by the testing organization. The test ~~contaminant~~ compound used for the gaseous challenge uniformity test may be different from the air cleaner test ~~contaminant~~ challenge compound, but it should be injected at the same temperature and at the same flow rate as the device test ~~contaminant~~ challenge compound will be, and it should have the same or a lower gas diffusivity. Because particle diffusion rates are lower than those of gases, a current qualification of the test duct as a Standard 52.2<sup>4</sup> test duct shall be deemed sufficient evidence of adequate mixing, provided that the ~~gas-contaminant~~ challenge compound is injected at or upstream of the aerosol injection point using a single- or multiple-injection point.

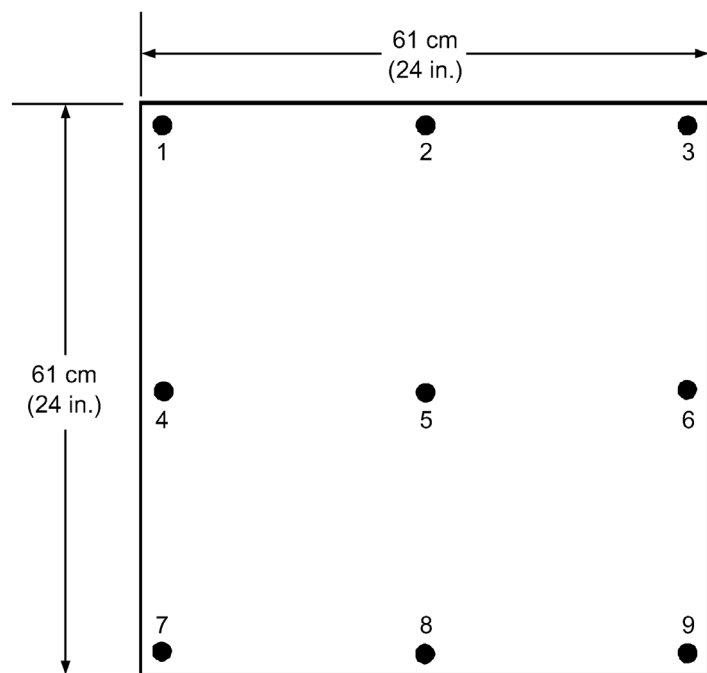
**5.6.2 Uniformity Requirement.** The uniformity of the challenge ~~gas-contaminant~~ compound concentration across the duct cross section shall be determined by a 9-point traverse in the 0.61 × 0.61 m (24 × 24 in.) duct immediately upstream of the device test section (i.e., at the location of the upstream sample probe), using the grid point locations shown in Figure 5-1. The traverse may be accomplished either by using 9 sample probes of similar design or by repositioning a single probe. Sharp-edged, isokinetic sampling probes such as those used in Standard 52.2<sup>4</sup> testing are acceptable but not required for gaseous ~~contaminant~~ compound sampling.

**5.6.3 Measurement.** The gaseous ~~contaminant~~ compound concentration measurements during the traverse shall be made with the appropriate gaseous ~~contaminant~~ compound analyzer. The details differ for different analyzers. Continuous analyzers shall be operated long enough to stabilize. Intermittent sample analyzers (a concentrating GC, for instance) shall be flushed to obtain a valid sample. For some difficult ~~contaminants~~ compounds, uniformity may be best established using surrogate compounds having similar gas diffusivities. A representative sample appropriate for the analyzer (a 1 minute or longer duration is recommended) shall be taken at each grid point with the ~~contaminant~~ challenge compound generator operating. After sampling all 9 points, the traverse shall be repeated 4 more times to provide a total of 5 samples from each point. The 5 values for each point shall then be averaged to obtain a mean and standard deviation. The traverse measurements shall be performed at airflow rates of 850 and 3400 cmh (500 and 2000 cfm). A CV of the corresponding 9 grid point concentrations of 15% or less for each airflow rate is required as evidence of spatial uniformity within the duct.

**5.6.4 Time Variability.** The variability of the challenge with time shall be evaluated during each test by the series of upstream challenge concentration measurements. The results of the test shall be reported as having been obtained at the mean of the several upstream measurements. The CV of the upstream measurements shall be 5% or less for the test to be valid, with a maximum deviation from the mean of 10%. Meeting this specification may require that the challenge ~~contaminant~~ compound generation system be started up and brought to steady state by offline operation.

## 5.7 Downstream Mixing of Challenge Compound~~Contaminant~~

**5.7.1 Overview.** A mixing test shall be performed to ensure that all ~~gaseous-contaminant~~ challenge compound that penetrates or bypasses the air cleaner is detectable by the downstream sampling probe. In brief, the test is performed by injecting a suitable tracer chemical at several designated points near the air cleaner test location and sampling downstream. (If it were the case that the mixing was perfect, then all downstream



**FIGURE 5-2 Injection grid with 9 points to assess downstream mixing. Perimeter points are 25 mm (1 in.) from duct wall.**

samples would report identical concentrations.) The downstream mixing test shall be performed at airflow rates of 850 and 3400 cmh (500 and 2000 cfm). A current qualification of the test rig for Standard 52.2<sup>4</sup> testing shall be considered sufficient to satisfy this requirement. If a Standard 52.2 downstream mixing test has not been performed, the test is to be conducted with a single contaminant compound having the same or lower gas diffusivity than the planned test-contaminant challenge compound. In overview, the test consists of injecting contaminant gas as a surrogate for a pinhole leak in the air cleaner. The point of gaseous contaminant compound injection shall be immediately downstream of the test air-cleaner location, and the injection point shall be traversed to cover a grid, as shown in Figure 5-2. The downstream sampling probe shall remain stationary at its normal center-of-duct sampling location. This test is best performed with a contaminant compound for which a near real-time analyzer is available.

**5.7.2 Upstream Background.** The downstream mixing test requires that no significant background level of the compound be present upstream of the injection point; a level of concentration below the detection limit of the instrumentation is preferable. ~~However, to avoid penalizing more sensitive equipment, backgrounds that would not be considered significant relative to expected test challenges shall be considered acceptable. Low or undetectable concentrations may be accomplished by operating the test duct with clean-up beds in place, no contaminant being injected, and a filter (gaseous or particulate filter) in the test location to provide flow smoothing. With no contaminant being injected, a sample collected at the downstream sample nozzle shall be below the analyzer detection limit or be low enough to be insignificant. Air concentrations of the challenge compound in the test rig prior to injection shall be < 1% of the challenge concentration before starting the mixing test.~~

**5.7.3 Tracer Contaminant Compound Injection.** The gaseous contaminant compound mass injection rate shall be such that a fully mixed downstream sample would have a concentration at least 10 times the analyzer detection limit and be within the calibrated range of the analyzer. Using a flexible tube, a rigid injection tube that is 12.7 mm (0.5 in.) or smaller in diameter, and has a length sufficient to reach each of

the injection points, is connected to the gas ~~contaminant~~ compound generator outlet. A 90 degree elbow at the end of the injection tube is turned so that the gas will be injected in the direction of the airflow. The flow rate through the gas ~~contaminant~~ compound injection tube and the diameter of the injection tube outlet are adjusted to provide an injection air velocity within  $\pm 50\%$  of the mean duct velocity. The expected downstream concentration is calculated based on the assumptions of 100% transport and perfect mixing. The tracer ~~contaminant~~ compound is injected ~~close downstream, within 25 cm (10 in.) of the flow smoothing filter~~ downstream and close to (within 25 cm or 10 in.) the test device slot at preselected points located around the perimeter of the test duct, and at the center of the duct as indicated in Figure 5-2.

**5.7.4 Tracer Analysis.** Prior to beginning the test, the ~~contaminant~~ compound analyzer shall be turned on and the standard daily operation checks performed. The analyzer is connected to the downstream probe sample system, whether it is a single-point or multipoint analyzer. With no ~~contaminant~~ compound injected, the analyzer should read zero or a value that is below the predetermined significant detection limit. ~~Contaminant~~ Compound injection may begin at any one of the points in Figure 5-2. Allow 1 minute (or at least three times the nominal transport time from injection point to sample location for internal mixing) before reading the analyzer. Take a second reading after 2 minutes. The two readings should be approximately the same and should be approximately the expected concentration. If not, the reason for the discrepancy should be determined and the test repeated after correcting the problem.

After this sample concentration has reached equilibrium, acquire a 1-minute integrated sample or average multiple samples over a 1-minute period. If an analyzer requires more than a 1-minute sample, this is acceptable. However, it is recommended that the ~~contaminant~~ compound/analyzer combination chosen for this test allow approximately 1-minute samples or averages. Record this value as the concentration for the first injection grid point. The injection tube shall then be moved to the next grid-point location and the process repeated, beginning sampling after 1 minute and obtaining samples over the next minute. The procedure shall be repeated until ~~contaminant~~ compound has been injected at all 9 grid points and samples have been obtained at each point.

**5.7.5 Replication.** The gas ~~contaminant~~ compound injection traverse shall be repeated two more times to provide triplicate measurements at each grid point. The downstream gas ~~contaminant~~ compound concentration shall be measured at the normal center-of-duct position. These triplicate measurements shall be averaged to provide a mean downstream concentration for each upstream injection point.

**5.7.6 Data Analysis.** The mean and sample standard deviation of the 9 downstream measurements shall then be computed. The CV of the measurement shall be less than 10% for each airflow rate.

**5.8 Challenge Compound~~Contaminant~~ Generation System Airflow Rate.** The test duct as specified in this method was developed with a challenge compound~~gas-contaminant~~ injection system airflow rate of 1% or less of the total test airflow. This challenge compound~~gas-contaminant~~ generator flow rate limit is established to ensure adequate transport and mixing while minimizing its impact on the conditioned test duct temperature and RH. This has been found to be suitable for many compound~~secontaminants~~ but is not a rigid requirement, provided that the environmental control specifications can be met. This shall be done for each gas generation system.

## 5.9 Gas Sampling and Analyzer Operation

**5.9.1 Requirements Overview.** Real-time gas analysis systems shall be zeroed (or have the zero verified) and calibrated at approximately 10%, 50%, and 100% of the planned challenge concentration for the challenge compounds~~gas-contaminant-gases~~ to be tested. Normal quantitative analysis considerations

should be applied to choose the calibration gas mixture and to avoid interferences. Analytical chemistry skills are required. In addition, the zero and span for each analyzer in use should be checked daily, if appropriate, for the instrument. For sampling pumps, calibration shall be conducted at least daily. For sampling tubes or other pull samples, the analyzer calibrations shall be done by the analytical lab. Some methods require use of a blank (non-pumped) sample for comparison. For in-house labs, these should be documented with the test labs QA. For external labs, the test reports should include calibration information and be acceptable for this test.

**5.9.2 Analyzers Specifics.** Analyzers requirements shall be taken into consideration in test setup. Some analyzers have specific inlet pressure requirements; others have specific flowrate requirements. Care must be taken to study the analyzers requirements and to set up the tests such that the analyzers conditions during the test runs are comparable to those of the calibration samplings.

**5.9.3 Analyzer Interference.** When a multiple-gas challenge (optional) is to be used or when by-products are likely, it is important to determine whether any of the gases will cause interference in any of the analyzers. If interference is possible, it shall be determined whether the interference will occur at an acceptable level and, if not, whether there is a way to eliminate the interference, or whether another analyzer must be used. For example, when multiple VOCs are used, a THC will not differentiate between them. If only the overall efficiency of the air cleaner with regard to the mixture is required, the THC is acceptable. However, if the efficiencies for the individual compounds are needed, a gas chromatograph may be required. If a GC is required, it shall be calibrated for each gas.

**5.9.4 Response Times.** Analyzer and sampling system response times should be minimized at all times and must be chosen such that they accomplish the intent of the test. Low flow-rate instruments, if they are drawing all the sample, may have a long sample transport time and limited resolution on the breakthrough curve. A supplementary sampling system with a high sample rate and consequent low sample residence time may be required. Note that for the lowest concentration, sampling and analysis may require samples to be taken and analyzed after the air cleaner challenge test is finished. Care should be taken to record the beginning and the ending sampling time and to take into account time delays in the sampling system when reporting the sample time.

**5.9.5 By-product Sampling.** For any test with a challenge compound containing carbon, except CO<sub>2</sub>, production of aldehydes or VOCs as by-products is possible. Appropriate sampling devices shall be used to sample for aldehydes and VOCs using at least one of the analysis techniques listed in Section 3.3. The pumps for the samplers should be calibrated or checked for correct airflow as directed by the test method, the sample device directions, and the pump requirements. Sampling times shall be chosen based on the requirements of the test method and devices to provide detection levels at 1% or lower of the upstream concentration and not higher than 5 ppb. Interferents shall be eliminated or reduced as much as possible for the specific challenge compound/contaminant, sampling device, and analysis method combination.

Direct sampling to non-sorbent tube analytical techniques may be used if all of the required compounds can be evaluated.

QA at least at the level required in 5.8.1 for real-time analyzers shall apply to the analysis of sampling devices. If this occurs in-house, the data requirements of the sampling method should be followed. If samples are sent to an external lab, documentation from that lab should be included in the test report.

**5.9.6 Ozone Sampling.** Ozone as a possible by-product or emission, shall be sampled using the same analytical procedures as for an ozone test.

**5.10 Rig Background Check.** Before testing begins, the background levels of challenge compounds~~contaminants~~ shall be shown to be acceptable. Sampling with the airflow on and the temperature and RH within specified limits shall be done at the upstream sampling location. Air concentrations of the challenge ~~gas~~ compound in the test rig shall be measured at  $< \pm 2\%$  of the initial removal efficiency challenge concentration from both upstream and downstream sample ports. Air concentrations of all by-product compounds in the test rig shall be  $< 5$  ppb or below the detection limit of the analytical device, whichever is higher. If these levels are not met, the inlet air cleaners are not working well and shall be changed.

Performing this check regularly for all compounds used in the lab may help determine when penetration begins to help determine when replacement cleanup beds will be needed.

This test is not required to be performed separately from the test procedure. Data taken during the correlation test are sufficient.

**5.11 Challenge Compound**~~Contaminant~~ **Generator and Duct Response Time.** This section was developed with the assumption that the challenge compound~~contaminant~~ generation system for the initial efficiency (low concentration) test was fully operational and nearly stable at the time challenge compound~~contaminant~~ injection began. The test device can therefore be installed in the test duct prior to the test and brought to equilibrium at test conditions. The actual test begins when challenge compound~~contaminant~~ injection starts. This criterion can be easily met with compressed gas cylinders but is more difficult with a liquid vaporization system. The purpose of the response time measurement is to ensure that the duration of the test is accurately known. As the standard capacity test will be performed at a different concentration, a separate response time test will be needed if the generator varies significantly from that used for the initial efficiency test.

Beginning with clean air in the duct at an airflow rate of 3400 cmh (2000 cfm), the time interval for the challenge compound~~contaminant~~ concentration to go from background level to a steady test level is measured. The test is performed with the gas analyzer sampling from the upstream probe. Once the upstream readings are stable, the time interval for the challenge compound~~contaminant~~ to return to background level after removal of the challenge compound~~contaminant~~ source (either by turning off the generator or by disconnecting it from the test rig) is measured.

These time intervals shall be used as the minimum waiting time between (a) activating the challenge compound~~contaminant~~ generator (or attaching the challenge compound~~contaminant~~ stream to the test rig, as appropriate) and beginning the sampling sequence and (b) deactivating or disconnecting the challenge compound~~contaminant~~ generator and beginning the analyzer sampling sequence for determination of background or post-challenge concentrations.

If the ~~sampling for a test requires sample collection and later analysis, the response time test should be performed using a surrogate gas that can be measured with a real-time analyzer, at a concentration and with a real-time analyzer that can sample the compound being used and the concentration such that the duct response time can be determined.~~ The generator shall be used in the same manner as it will be used at the test concentration. For example, for a vaporized liquid generator, the combined challenge compound~~contaminant~~ and carrier stream should be introduced at the same flow rate because the duct response will be dependent on how quickly the combined stream reaches the diffuser within the test duct.

**5.12 100% Removal Efficiency Filter Test and Purge Time Determination.** ~~An initial efficiency test shall be performed using a complete air cleaner as the test device to demonstrate that the test duct and~~

sampling system can provide a >99% efficiency measurement. The possible sources of error are inward leaks of clean air, losses to the test duct wall, or sampling system leaks and/or dead spaces. This test shall be conducted with readily adsorbed contaminants and a 10 kg (22 lb) or greater high-quality sorbent air cleaner with moderate grain size. The air cleaner shall be installed to be leak free, and the test contaminant chosen shall be one that is easily removed. The purpose of the test is to demonstrate that initial removal efficiency can be determined to be >99%. The test shall be performed using a combination of challenge compound and an air cleaner that has been demonstrated to achieve an initial removal efficiency of close to 100%. An example of an appropriate combination is Toluene with a 10 kg (22 lb) or greater high-quality activated carbon air cleaner with moderate grain size. The computed removal efficiency values shall be greater than 99% for the ~~test contaminant~~ challenge compound. For the purposes of the 100% removal efficiency test, the initial removal efficiency test only needs to be run long enough to show the >99% measurement. This must include at least 5 downstream measurements.

One parameter affecting the efficiency during the 100% efficiency test is the purge time required to sweep ~~challenge compound~~ ~~contaminant~~ out of the duct and sample lines. ~~Challenge compounds~~ ~~Contaminants~~ may adsorb on the duct walls, so sample lines will require a limited but potentially significant length of time to clear. The purge time is too short if, after switching from the upstream to the downstream line, residual ~~challenge compound~~ ~~contaminant~~ gas from the upstream sample is detected during the downstream sampling and yields an efficiency of <99%. If this occurs, the purge time shall be increased and the 100% efficiency test repeated.

**5.13 No-Air-Cleaner Test and Overall System Check.** An upstream/downstream comparison test is performed without a test device in place to check the adequacy of the overall duct, sampling, measurement, and ~~challenge compound~~ ~~contaminant~~ generator. The test shall be performed at the test velocity and using the ~~challenge compound~~ ~~contaminant~~ generation system at the challenge ~~contaminant~~ ~~compound~~ concentrations for the current test sequence. Based on measured ~~challenge compound~~ ~~contaminant~~ injection rates and duct airflow rates, the expected upstream ~~challenge compound~~ ~~contaminant~~ concentration is computed. The analyzer is used to measure the upstream ~~challenge compound~~ ~~contaminant~~ concentration. The difference between the expected and actual measured concentrations should be less than 10% of the measured concentration. The analyzer is used to measure the downstream ~~challenge compound~~ ~~contaminant~~ concentration for comparison to the measured upstream ~~challenge compound~~ ~~contaminant~~ concentration. The efficiency shall be calculated according to equations (10-1) and (10-2) and shall be <5%. For challenge concentrations less than or equal to 100 ppb  $\pm$  10% is acceptable. The upstream/downstream concentration ratio from the no-filter test shall be ~~used to correct~~ multiplied by the measured downstream concentrations during the device test to account for minor systemic losses or enrichments.

**5.14 Gas Analyzers and Sampling System Zero.** With the ~~challenge compound~~ ~~contaminant~~ generation system turned off or disconnected (and venting someplace safely), the concentrations in the test rig shall be determined with all equipment to be used for both portions of the test. The concentration determined by the gas analyzers sampling from the upstream and downstream sample points shall be verified to be below the analyzer detection limit (as determined during calibration) or lower than otherwise required (e.g., less than 5% of the upstream concentration for an air cleaner with 50% breakthrough expected) for the sample protocol to be used during the test. Since the gas sampling devices cannot be run and checked on the day of the test due to time needed to get the analysis done, these samples should still be collected and the test be run if the real-time analyzer indicates that the rig is clean enough.

**5.15 Test Duct Air Temperature Measurement and Control.** The test air temperature in the duct, depending on the control system design, will often have a periodic nature resulting from the nature of the temperature control system. That is, the temperature varies about the setpoint between lower and upper

control limits. The period of the function will depend on the design. For the purposes of this test, the temperature measurement device on which control is based is required to have an accuracy of 0.1°C (0.2°F) and to be calibrated regularly. The air temperature shall be measured using a single probe located near the upstream sample inlet. Should the probe be heat traced for challenge compound~~contaminant~~ transport, ensure that the air temperature measurement is not affected. Continuous temperature measurement is not required. However, the temperature shall be measured and recorded frequently enough to define the periodic nature of the duct temperature (10 times per cycle) or at least once per minute during the biannual qualification test. The test air temperature is required to be controlled within  $\pm 2^{\circ}\text{C}$  (3.6°F) of the mean temperature.

**5.15.1** Temperature shall be monitored periodically during an actual test, but the frequency of monitoring may be less than is required for this test.

**5.16 Test Duct Air Relative Humidity Measurement and Control.** The test air RH in the duct, depending on the control system design, will often have a periodic nature resulting from the nature of the temperature and RH control systems. That is, the humidity varies about the setpoint between lower and upper control limits. The period of the function will depend on the design. For the purposes of this test, the RH measurement device on which control is based is required to have an accuracy of 2% rh in the range of 30% to 70% rh and to be calibrated regularly. The air humidity shall be measured using a single probe located near the upstream sample inlet. Should the probe be heat traced for challenge compound~~contaminant~~ transport, ensure that the air humidity measurement is not affected. Continuous RH measurement is not required. However, the RH during each test shall be measured and recorded at least once per minute and frequently enough (10 measurements per cycle) to define the periodic nature of the duct RH during the biannual qualification test.

The test air RH is required to be controlled within  $\pm 5\%$  rh of the mean RH. RH must be monitored periodically during an actual test, but the frequency of monitoring may be less than is required for this test.

### **5.17 Downstream Challenge Exhaust Air Cleaners.**

**5.17.1 General.** In the once-through mode, the gas stream, after contacting the test air cleaner, is ultimately directed to a building roof vent. To minimize the environmental impact of the challenge compound~~contaminant~~ gases and meet local and institutional requirements, exhaust air cleaners (likely scrubber cartridges) may need to be installed. These air cleaners serve no purpose until the challenge compound~~contaminant~~ has begun to pass through the air cleaner under test. From this point in the test until its conclusion, the exhaust air cleaners should remove enough of the challenge gas compound to meet effluent requirements.

**5.17.2 Performance Monitoring.** The performance of the exhaust air cleaners is readily monitored by adding an additional switched sampling line downstream of the exhaust air cleaners. This line is not required to be activated until a significant challenge compound~~contaminant~~ penetration is determined through the cartridge filter under test. Timed, sequential sampling (upstream of test air cleaner, downstream of test air cleaner, and down- stream of exhaust air cleaner) by the challenge compound~~contaminant~~ analyzer will provide a record of the performance level of the exhaust air cleaners during the test period. These data will also provide a means of determining the total ppm-hours of exposure for exhaust air cleaners as a guide to estimating their expected remaining capacity, prior to the start of a challenge test.

**5.17.3 Selection.** The selection of the exhaust air cleaner is left to the user, as the effectiveness required to meet local exhausting requirements varies. An important criterion is the added resistance to airflow imposed on the test section by these air cleaners. The additional resistance to airflow should be limited to less than



250 Pa (1 in. of water) and shall be included in the total pressure upper limit of 1.25 kPa (5 in. of water) for the test method. The user shall consider by-products that may be generated with certain air cleaning technologies when selecting the exhaust air cleaner.

**5.18 Resistance to Airflow Across Empty Duct Section.** The resistance to airflow across the empty test section shall be measured as part of each no-filter test performed in accordance with Table 5-2. The measured resistance to airflow across the empty test section shall be less than 8 Pa (0.03 in. of water). System maintenance shall be performed until the resistance to airflow is below 8 Pa (0.03 in. of water).

**5.19 Qualification Maintenance.** Duct and instrumentation qualification maintenance items are provided in Table 5-2.

## 6. TEST CONDITIONS AND MATERIALS

This section defines standard and optional test conditions and materials. Standard test conditions are defined to provide users of air-cleaning technology a meaningful standard point of comparison between different air cleaners that can be obtained at moderate cost. The standard test is conducted with selected challenge compound contaminants at a fixed concentration, temperature, and RH and at the design flow rate for the air cleaner. Inherent in this standardization is the consequence that such a standard test provides removal efficiencies, breakthrough times, and removal capacity data for only a single test condition, and these results may be significantly different from the actual performance under use conditions.

While the value of this standard test is significant, tests closer to actual use conditions provide air-cleaner performance data that is more useful for specific applications and even for classes of applications. Therefore, this standard allows the use of the test duct to conduct optional tests at conditions other than the standard test conditions. The permitted changes allowed include variations in challenge chemicals and concentrations, temperature, RH, and device flow rate. It may be that user requirements are best served by testing over a range of parameters. For example, a particular range of RHs might better characterize air cleaners used in low-moisture locations such as Phoenix, AZ, as compared to high-moisture locations such as Houston, TX. Similarly, because capacity data for a given air cleaner are almost certainly concentration dependent, it may be reasonable to require both low- and high-concentration testing to simulate different challenge scenarios. All optional test results shall be clearly marked as being from an optional test, include clearly marked test conditions, and include the “optional test” notice as required in Section 6.2.

### 6.1 Standard Test Conditions, Test End Point, and Challenge Chemicals

**6.1.1 Standard Test Objective.** The objective of the standard test is to provide, at a moderate test cost, comparative performance data for full-scale air cleaners. The data shall be obtained at fixed temperature and RH and at the air cleaner’s design flow rate. For EAC, the device should be operated on the highest setting if there is more than one level controlled by a switch. Alternately, the device should be operated using conditions that yield maximum efficiency. The setting used must be noted clearly on the test report. The test is separated into two parts to allow a determination of an initial performance at a concentration near to that likely to be encountered in indoor air and a choice of two follow-on options. For devices, like EAC, that are unlikely to retain significant amounts of the challenge compound, the continued low concentration test provides a way to show that the devices have consistent performance over a longer period of time than the initial removal efficiency test. If the removal efficiency is stable, a stable-over-5-hour result will be noted. For devices that are expected to retain challenge compounds and to have changing removal efficiency, the second option of determination of removal capacity and removal efficiency at an elevated concentration is preferred.

The initial, low-concentration test is designed to give the performance values of a new air cleaner at expected use concentrations. As significant penetration through adsorbent air cleaners may take weeks or months, a removal capacity test is conducted for this type of air cleaner at elevated challenge concentrations to shorten the test, thereby reducing its cost. Thus, the standard removal capacity test results will not normally provide performance data that are directly transferable to use conditions. Extrapolation of the standard test results to use conditions will in some cases be reasonable but in other cases will not.

For all air cleaners, once the challenge has been stopped, a desorption check is performed to determine if the air cleaner retains the challenge compound.

The ~~corrected~~ removal efficiency from this test, ~~which incorporates by-product test data,~~ shall be used to evaluate air cleaners for use in a building either designed or operated using the IAQ procedure from ASHRAE Standard 62.1. This is the efficiency that shall be used as the Ef for the IAQ procedure. Emission rates for each by-product identified from the by-product test shall be used in a building either designed or operated using the IAQ procedure from ASHRAE Standard 62.1. This is the generation rate that shall be added as source N in addition to other sources for the IAQ procedure.

**6.1.2 Standard Test Conditions.** The test air conditions for the standard test are as follows:

- a. Air temperature of 25°C (77°F) measured and recorded as described above.
- b. Air RH of 50% measured and recorded as described above.
- c. An airflow rate equal to the specified or design flow rate of the air cleaner.
- d. Initial background concentrations of challenge gas compound in the test rig measured, recorded (if a real-time analyzer), and determined to be  $< \pm 2\%$  of the challenge concentration.
- e. Initial background concentrations of all by-product compounds in the test rig measured, recorded (if a real-time analyzer), and determined to be  $< 5$  ppb or below the detection limit of the analytical device, whichever is higher.

### 6.1.3 Standard Test Endpoints

**6.1.3.1** The standard initial removal efficiency test shall be conducted for a period of 1 hour. ~~At this point~~ Immediately after this is complete, either the low concentration challenge ~~gas~~ shall be continued for 4 more hours, or the low concentration challenge shall be turned off, and the standard removal capacity test should begin as soon as possible after this test. The continued low concentration test should be used for devices that are expected to have constant removal efficiency over time; the removal capacity test should be used for air cleaners that are expected to have a typical sorbent breakthrough curve with the removal efficiency decreasing over time, but a large removal capacity for the challenge compound ~~contaminant~~ before this decrease. Thus, many EAC will test with the continued low concentration to show the capability for extended stable removal efficiency while sorbent air cleaners will usually be better tested with the removal capacity test. This choice should be made by the manufacturer or the purchaser of the test.

**6.1.3.2** The continued low concentration test is simply an additional 4 hours of the low concentration challenge. At this point, the challenge gas compound shall be turned off and the downstream concentration monitored for up to 30 minutes or until the downstream concentration goes below 10% of the test's upstream concentration, whichever is reached first. Desorption measurements following low concentration testing are not directly comparable to desorption measurements following the standard removal capacity test at elevated concentration.

**6.1.3.3** The standard removal capacity test shall be conducted with ~~a single~~ the same challenge ~~gas compound~~ for up to 4 hours or until a penetration of 95% or greater (downstream concentration measurement equal to  $\geq 95\%$  of the challenge) is achieved. At this point the challenge ~~gas compound~~ shall be removed (turned off or diverted) and challenge ~~gas compound~~ desorption shall be monitored until the concentration is reduced to 10% or less of the test challenge concentration, or for 30 minutes, whichever is reached first.

**6.1.4 Standard Test Gases.** This test shall be performed with a single gas. While only one gas is required for the test to be valid, it is recommended that each air cleaner type be tested with a VOC, an acid gas, and another gas selected from those listed in Table 6-1, as appropriate to the air cleaner. However, if an air cleaner is intended to be used where one of these categories is not present, it should be tested with gases that are applicable to its use. The currently defined standard challenge ~~gases~~ compounds are shown in Table 6-1. The gases are listed by category, with one of the gases in each category cited as being required for the test. If any other gas in a certain category is tested, then the required gas for this category must also be tested for the test to be considered a valid Standard 145.2 test. If the required gas for a category is incompatible with the air cleaning device, this shall be documented in the Remarks section of the Test Report under Test Conditions.

**TABLE 6-1 Standard Test Challenge Compounds Gases**

Category/Chemical	CAS #	MW <sup>a</sup>	Low Conc. (ppb)	High Conc. (ppm)	NIOSH REL TWA (ppm) <sup>b</sup>	OSHA PEL TWA (ppm) <sup>b</sup>	High Conc. Rationale <sup>c</sup>	Capacity Used <sup>d</sup>	Required Chemical
<b>Acid Gases</b>									
Sulfur Dioxide	7446-09-5	64.1	50	35	2	5	AA	6%, x 8%, y <sub>b</sub>	<input checked="" type="checkbox"/>
Hydrogen chloride	7647-01-0	36.5	75	5	5 (c)	5 (c)	DD	12%, y <sub>b</sub>	
Hydrogen sulfide	7783-06-4	34.1	100	25	10 (c)	20 (c)	CC	12%, x 20%, y <sub>b</sub>	
NO <sub>2</sub> <sup>±</sup>	10102-44-0	46.0	50	30	1 (st)	5 (c)	AA	6%, z 20%, x	
<b>Aldehydes</b>									
Formaldehyde	50-00-0	30.0	100	1	0.016	0.75	EE	3%, x	
Acetaldehyde	75-07-0	44.1	100	15	None	200	AA	10%, x	
Hexanal	66-25-1	100.2	100		None	None			
<b>Basic Gases</b>									
Ammonia	7664-41-7	17.0	100	75	25	50	AA	5%, y <sub>a</sub>	<input checked="" type="checkbox"/>
Methylpyrrolidone	872-50-4	99.13	100	5	None	None	AA	15%, xy <sub>a</sub>	
<b>Oxidizing Gases</b>									
Ozone	10028-15-6	48.0	100	0.5	0.1 (c)	0.1	BB	None	<input checked="" type="checkbox"/>
<b>VOCs</b>									
Toluene	108-88-3	92.1	400	50	100	200	AA	20%, z	<input checked="" type="checkbox"/>
2-Butanone (MEK)	78-93-3	72.1	400	65	200	200	AA	20%, z	
Acetone	67-64-1	58.1	400	20	250	1,000	AA	5%, z	
Benzene	71-43-2	78.1	400	60	0.1	1	AA	20%, z	
Cyclohexane	110-82-7	84.2	400	55	300	300	AA	20%, z	
Cyclopentane	287-92-3	70.2	400	50	600	None	AA	15%, z	
Dichloromethane	75-09-2	84.9	400	50	None	25	AA	20%, z	
Ethanol	64-17-5	46.1	400	50	1,000	1,000	AA	10%, z	
Hexane	110-54-3	86.2	400	25	50	500	AA	10%, z	

iso-Butanol	78-83-1	74.1	400	45	50	100	AA	15%, z	
Isopropanol	67-63-0	60.1	400	35	400	400	AA	10%, z	
Tetrachloroethene	127-18-4	165.8	400	25	None	100	AA	20%, z	
m-Xylene	108-38-3	106.2	400	45	100	100	AA	20%, z	
o-Xylene	95-47-6								
p-Xylene	106-42-3								
<b>Warfare</b>									
DMMP (Dimethyl methylphosphonate)	756-79-6	124.1	75	20	None	None			<input checked="" type="checkbox"/>
<b>Miscellaneous</b>									
Chlorine	7782-50-5	70.9	100	30	0.5 (c)	1 (c)	AA	10%, z 12%, y <sub>b</sub>	None
Carbon Monoxide	630-08-0	28.0	100	35	35	50	DD		
Carbon Dioxide†	124-38-9	44.0	1100	5,000	5,000	5,000	DD		

Notes:

- Molecular Weight
- Includes NIOSH Recommended Exposure Limits and OSHA Permissible Exposure Limits that have been vacated. The values are time-weighted averages unless otherwise indicated as follows: c = ceiling value, st = short term
- Rationale for the Recommended High Concentration is as follows:  
AA = Based on the concentration of gas required to consume 2 ft<sup>3</sup> of media at 2000 cfm in 8 h BB = based on consideration of safety, health, and reactivity with materials of construction CC = based on consideration of safety, health, and low odor threshold  
DD = based on NIOSH and OSHA TWAs  
EE = based on considerations of safety and health
- Capacities taken from standard industry sources such as the carbon tables. Media types indicated below:  
x = permanganate-impregnated activated alumina  
ya = acid-impregnated activated carbon yb = base-impregnated activated carbon z = virgin activated carbon, bituminous  
+Challenge compound gas shall be NO<sub>2</sub>; analysis shall be performed for both NO<sub>2</sub> and NO.  
† Units for Low Concentration for Carbon Dioxide are ppm.

## 6.2 Nonstandard Test Conditions, Test End Point, and Challenge Chemicals

**6.2.1 Nonstandard Test Objectives.** Nonstandard tests are those conducted using the test methodology of this standard with nonstandard test conditions and/or materials for the purposes of the end user or the manufacturer. In addition, an otherwise valid standard test that was conducted (inadvertently or deliberately) at a nonstandard temperature or RH is permitted to be reported as a valid result of a nonstandard test.

**6.2.2 Reporting Nonstandard Tests.** The testing organization is required to report the test as a nonstandard test and to record the actual test conditions, end point, and challenge chemicals on all documents and reports related to the test.

## 7. PREPARATION OF THE TEST DEVICE

The test air cleaner shall be equilibrated to the test environmental conditions prior to beginning the challenge testing. The time required for equilibration will depend on the technology being tested. Adsorption-based devices are likely to require longer equilibration periods than energetic devices, although UV lamps may need to be burned in for 100 h before the test. If not specified otherwise by the manufacturer, the following in-duct equilibration procedure shall be used:

- Prior to air cleaner installation, operate the test duct to control clean air to the desired test temperature and RH. While operation at full test flow rate will not always be necessary to equilibrate an air cleaner, the equilibration period is a good time to establish the test conditions and stabilize the test duct.
- Install the test air cleaner in the manner that is appropriate for the test. For EAC, be sure they are correctly conditioned (see instruction manual) and are plugged in.

- c. Pass conditioned air through the test air cleaner for 30 minutes or until the upstream and downstream temperature and humidity readings are approximately equivalent: temperatures within 2°C (3.5°F) and RH within 5%.

## 8. TEST PROCEDURES

**8.1 Test Conditions.** The test conditions shall be as follows:

- a. Airflow rates shall be at the manufacturer's specified flow rate for the air-cleaning device. The resistance to airflow at that flow rate shall be a measured parameter.
- b. The temperature and RH for the test shall be set and controlled to the test requirements of Section 6.
- c. The test challenge chemicals and concentration shall be set as described in Section 6.
- d. Test termination shall be determined as discussed in Section 6.
- e. Following termination of challenge compound ~~contaminant~~ injection, the air cleaner shall be purged with challenge-free, conditioned air to evaluate any desorption as described in Section 6.

**8.2 Test Sequence.** ~~For a complete test of the air cleaner, the sequence of steps shall be as follows~~ This test procedure assumes that, prior to beginning this procedure, the test operator has tested and validated the challenge compound ~~contaminant~~ generation system and the duct flow system. The test shall be conducted as follows:

- a. Prior to installing the air cleaner for challenge testing, start the test duct and the sampling and analysis systems. Perform routine calibration checks and record the results. Monitor/measure upstream concentrations for all compounds to be analyzed in the challenge test. Establish that the duct background for the challenge gas compound is below the detection limit or is acceptable, as specified in Section 5.9.
- b. Verify that the temperature and RH conditions are at the desired test settings. Start the challenge gas compound injection into the test rig at one of the two concentrations that will be used. It can be recommended to start with the higher concentration. The challenge compound generator settings should be recorded to use in the lab's established protocol at the next point where a quick step change to the concentration is needed. If use of the settings is not sufficient to achieve a quick, less than 2-minute step change, leaving the generator running but bypassing the test duct is recommended so that the challenge compound flow can be quickly reestablished.
- c. Once the concentration has stabilized, obtain at least 3 upstream and 3 downstream samples for the no-filter test for each analyzer or pull sample that is to be used in the test, as required in Section 5.9. If these data meet the test specifications as detailed in that section, continue with step (d). Otherwise, perform maintenance or system adjustments until the no-filter requirements are met and restart the test. For tests with real-time sampling, these data may be used. In studies using non-real time sampling techniques (e.g., pull samples), one cannot determine the correlation value (no air cleaner penetration value) at this point. In this case, the previously completed QA test (see Section 5) will be considered sufficient to proceed with the test. However, if these actual test data fail the requirements, the test should be considered out of specification and will need to be repeated.
- d. Disconnect the challenge gas compound injection (feed stream) from the test rig or otherwise redirect the challenge gas compound so that it does not enter the test section, making sure that the challenge gas compound is being vented safely.
- e. Repeat steps c and d for the other (either low or high) concentration.
- f. Purge the test rig in preparation for opening it to insert the test air cleaner. The time required to do this will depend on the test rig setup, but it should not be more than a few minutes. The criterion for completing the purge is to avoid exposure of the test rig operators to excessive concentrations of the

challenge ~~gas~~ compound and to lower the rig concentrations below those required for the initial efficiency test. Following the purge period, stop or slow down the airflow such that the access doors can be opened.

- g. Open the doors of the test rig and install the air cleaner. Check to ensure that the installation is leak free for devices intended to seal into the rig. Proper installation ensures that there is no unintended by-pass around the air cleaner. Also check to ensure that leaks inherent in the air-cleaner housing, as supplied to the test lab, are not sealed. For EAC, be sure the power cord runs through a well-sealed opening and is accessible. Be sure the air cleaners can be turned on from outside of the test rig and that they do not have airflow switches that will turn them off during the test when they should be on.
- h. Close the door of the test rig. Start the airflow through the air cleaner. For EAC, turn on the device.
- i. Monitor and record the temperature and RH at least 10 times throughout the challenge test. Monitor and record the challenge pressure, the resistance to airflow across the air cleaner, and the ASME flow nozzle (orifice) resistance to airflow at least 2 times during the test.
- j. Allow the air cleaner to equilibrate to the test temperature and RH if it has not already been equilibrated during the testing described in Section 9.
- k. Perform resistance to airflow curve measurements according to the requirements of Section 9.5 if not performed previously.
- l. Using each sampling technique, analyzer, and sampling device, take at least 2 downstream concentration samples to determine if the air cleaner gives off or produces the challenge compound or other by-products.
- m. Using established procedures to quickly step up to the required concentration, sStart or reconnect the challenge gas compound injection at the initial removal efficiency (low concentration) level. For EAC, turn on the device. Start the test timer immediately. If using a single analyzer, measure upstream first for 5 minutes, then take downstream measurements continuously for 55 minutes. Then sample upstream for 5 minutes to confirm stability of the challenge concentration (< 10% difference between starting and ending upstream concentration; otherwise, the test shall be repeated). Downstream measurements shall be taken at equal time intervals. When using a single analyzer, it is the lab's discretion to take an upstream measurement after 30 minutes to confirm stability of the challenge concentration rather than wait until the end of the hour (based on analyzer parameters, stability of the challenge compound generation, and other considerations). For dual analyzer tests and for sampling device testing, sampling upstream and downstream shall cover 60 minutes. For sampling devices, this may be done as 60-minute samples or as shorter ones. Each sampling technique must be done in at least triplicate. For analyzers, this will be sequential samples and should be approximately 60-65 samples. When using gas sampling devices, this could be, for example, (Qty =) 3 60-minute upstream samples and 3 60-minute downstream samples or 3 sequential 20-minute samples upstream and downstream. Determine whether the difference between the expected and actual measured concentrations is less than 10% of the measured concentration as required in 5.13. If not, the test must be repeated.
- n. For an extended steady-state removal efficiency test, continue the low concentration exposure for 4 more hours. If using sampling techniques to determine the concentration of the upstream challenge compound, take enough samples to yield concentration curves for upstream and downstream with enough separate samples to allow determination of the removal efficiency at least for every hour increment. Note that the sample analysis must allow determination of the concentration of the specific challenge gas compound (simple TVOC measurements are not sufficient). Real-time analyzers shall collect samples from both upstream and downstream at least 10 each per hour. At 4 hours, stop the challenge and skip to step r desorption. Determine whether the difference between the expected and actual measured concentrations is less than 10% of the measured concentration as required in 5.13. If not, the test must be repeated.
- o. For the removal capacity test, stop the low-concentration challenge.

- p. For the removal capacity test, switch to standard removal capacity concentration generator or generator settings and to required analytical equipment.
  - q. Using established procedures to quickly step up the concentration, sStart standard removal capacity test challenge gas compound generation using the settings determined previously. ~~If necessary, remove the air cleaner while establishing the concentration. If possible, determine settings before the air cleaner is initially installed so that the transition may be smooth and made with the air cleaner in place.~~ Record the start time and all settings.
  - r. Operate according to Sections ~~8.1.3 and 8.1.5~~ 6.1.3.3 (standard challenge test of up to 4 hours or 95% breakthrough if this can be determined during test). For single analyzer systems, monitor downstream concentrations with regular checks on the upstream concentration. The first sample should be downstream. It is acceptable for repeated downstream samples to be taken before switching to upstream, especially if immediate high-level breakthrough is anticipated or seen in the data. For dual analyzers, upstream and downstream sampling should occur throughout the test. Pull samples or other non-real time sampling shall be done to determine the upstream and downstream concentrations of the challenge compound throughout the 4-hour period. For air cleaners that are known not to produce by-products for the specific challenge compound, measuring with a TVOC device is acceptable if the challenge is VOC. However, if the initial efficiency by-products tests come back showing by-products, the test will need to be repeated and those by-products accounted for. For air cleaners that produce by-products, the measurements must determine the actual concentrations of the specific challenge compound and by-products.
  - s. Stop the challenge compound~~contaminant~~ injection and continue the airflow. Continue the desorption run for up to 30 minutes or until the concentration is 10% or less of the test's challenge ~~contaminant~~ compound concentration. Continue sampling downstream for the desorption portion of the test.
  - t. Plot the upstream and downstream concentrations for the standard capacity test to define the shape of the break-through (if any) and the desorption curves, compared with the challenge concentrations, as in the example shown in Figure 10-1.
  - u. If testing an EAC, turn off the power.
  - v. Record the final air cleaner resistance to airflow.
  - w. Turn off the test rig and remove the air cleaner. If the downstream concentration exceeds acceptable levels for operator safety, it is recommended that airflow be continued through the air cleaner until the challenge gas compound is safely vented before removal.
- ~~a. Complete a leak characterization and personnel safety evaluation as described in Section 5 of this method, if needed.~~
  - ~~b. Visually inspect the air cleaner sealing surface, if there is one, for defects that might prevent proper sealing in accordance with Section 7.2.~~
  - ~~c. Install the air cleaner and conduct visual inspection for leaks in the mounting, if appropriate.~~
  - ~~d. Equilibrate the test air cleaner at the test conditions.~~
  - ~~e. Measure the resistance to airflow versus the conditioned airflow rate of the clean air cleaner as described in Section 9.~~
  - ~~f. Using established procedures to quickly step up the concentration, sStart the challenge chemical for the initial removal efficiency (low concentration) test. Measure upstream and downstream challenge (contaminant) concentration levels for the challenge contaminant, ozone, and for by product concentrations for exactly 1 hour. Then either continue the low concentration challenge for 4 more hours or stop the low concentration challenge gas if the removal capacity test is to be done.~~
  - ~~g. For the removal capacity test, start the challenge for the standard removal capacity test as soon as is practical after switching generator and/or analysis equipment. Measure upstream and downstream challenge (contaminant) concentration levels until the desired breakthrough occurs or until 4 hours has elapsed, whichever occurs first. Do not stop the challenge while a sample is being taken unless that~~

~~sample can be ignored. If an analytical technique is used that does not provide real time concentrations, continue testing for the entire 4 hours.~~

- ~~h. Follow either test with a desorption characterization period with no challenge.~~
- ~~i. Periodically monitor downstream of the cleanup exhaust air cleaners to determine their effectiveness, if needed.~~
- ~~j. Periodically monitor the operators' work areas to ensure that any leakage to the room is acceptable, taking steps to ensure that resulting concentrations are less than the applicable PEL, if needed.~~

## 9. MEASUREMENT OF RESISTANCE TO AIRFLOW VS. AIRFLOW

9.1 Install the test air cleaner. This test may be performed during the equilibration period.

For the purposes of this standard, airflow rate shall be defined by the following equations from ASME Standard MFC-3M-1989:

$$Q = 1.1107 \times 10^{-6} C \times D^2 \times \left\{ \frac{\Delta p}{[p \times (1 - \beta^4)]} \right\}^{0.5} \quad (\text{SI})$$

$$Q = 5.9863 \times 10^{-6} C \times D^2 \times \left\{ \frac{\Delta p}{[p \times (1 - \beta^4)]} \right\}^{0.5} \quad (\text{I-P})$$

where

$Q$  = test airflow rate, m<sup>3</sup>/s (cfm)

$C$  = coefficient of discharge = 0.9975–6.53 Re<sup>-0.5</sup>

$D$  = nozzle throat diameter, mm (in.)

$W$  = duct width, mm (in.)

$\beta = D/W$

$\Delta p$  = nozzle resistance to airflow, Pa (in. of water)

$\rho$  = humid air density at nozzle inlet, kg/m<sup>3</sup> (lb/ft<sup>3</sup>)

$\mu$  = humid air dynamic viscosity, Ns/m<sup>2</sup> (lbm/ft·s); at 25°C and 50% rh,  $\mu$  has the value of 1.817 × 10<sup>-5</sup> Ns/m<sup>2</sup> (1.22 × 10<sup>-5</sup> lbm/ft·s).

Re = Reynolds number =  $K\rho Q/\mu D$ ; at 25°C, 50% rh, and the units above, the conversion constant in the expression for Re,  $K$ , has the value of 5.504 × 10<sup>7</sup> (SI) or 16,393 (I-P).

The resistance to airflow across the nozzle shall be at least 100 Pa (0.4 in. of water) at the test airflow rate, and the nozzle position and static taps shall conform to Standard 52.2<sup>4</sup> requirements.

After the air cleaner has equilibrated to the air conditions, measure and record the resistance to airflow of the device at a minimum of 5 flow rates. The highest flow rate used shall produce resistance to airflows below the maximum resistance to airflow allowed for the air cleaner. When possible, the resistance to airflow test flow rates should be approximately equally spaced and should bracket the device test flow rate (e.g., 0.5, 0.75, 1.0, 1.25, and 1.5 times the test airflow rate). Very low or high flow-rate devices (whose operating airflow rates are at either end of the test duct's operating range) may prevent bracketing.

## 10. DETERMINATION OF PERFORMANCE

This section describes the sampling sequence, data collection, and data analysis procedures for sequential upstream/down-stream sampling with either a single gas analyzer or dual analyzers. For tests requiring pull samples for later analysis (i.e., gas samples are passed through fixed media [in a sampling tube or cartridge]



or acquired in a bag sample [Tedlar bag]), real-time sampling of gases is not required. However, it is recommended to allow determination that the upstream concentration is in the correct concentration range and that the concentration(s) is/are stable, allowing a challenge test to be stopped if the penetration/efficiency specifications are reached. Challenge tests that do not meet specifications for upstream concentration and stability or that are stopped too soon are considered out of spec and not official 145.2 tests. Use of real-time analyzers can save the cost and time of repeating tests.

Dual analyzers are not required for routine gaseous air cleaner testing in accordance with this standard. In addition to routine upstream/downstream monitoring to determine the air-cleaner performance, additional monitoring is required downstream of exhaust air cleaners (to ensure environmental emission compliance for challenge removal prior to outside exhausting) and in the operator's work area (to ensure worker safety). Additional gas-phase air-cleaner performance theory is provided in Appendix C.

**10.1 Air-Cleaner Test Overview.** Prior to the start of testing, if the challenge ~~gas compound~~ concentration is high enough to exceed permissible exposure limits or a lab's safety protocol, the full system shall be characterized for leakage as required by Sections ~~5.3~~ 5.2 and 5.5, and the test duct operator working space concentrations are required to be found acceptable in accordance with the test facility safety plan.

The initial removal efficiency (low concentration) clean ~~filter~~ air cleaner test results shall be reported in tabular form, including the upstream and downstream concentrations of the challenge compound and by-products ~~shown~~ along with the average penetration and removal efficiency for the hour reported as the initial result. If distinct data points are taken over the time of the test, the data ~~may~~ shall be plotted with respect to time.

For the continued low concentration test, the ~~tabulated~~ data shall be reported as for the first hour test, in tabular form and plotted with respect to time if distinct data points are taken. Average penetration and removal efficiency shall also be calculated and reported for at least 3-time intervals during the 4-hour continuation.

For the standard removal capacity test, the inlet and outlet concentration data for the challenge ~~contaminant compound~~ shall be tabulated and plotted at the test conclusion to define the shape of the ~~concentration breakthrough~~ breakthrough curve ~~to the point of breakthrough~~ and to define the desorption/release curve following cessation of the challenge concentration. See Appendix C for a detailed discussion of breakthrough theory.

The 50% ( $t_{b50}$ ) time is a useful and relatively easily reproduced midlevel indicator of air-cleaner performance during the standard removal capacity test. The time to 95% breakthrough ( $t_{b95}$ ) and to 100% breakthrough are less commonly reported because of the experimental time required to make the determination. The 5% and 50% breakthrough times ( $t_{b5}$ ) and ( $t_{b50}$ ) shall be reported for ~~this~~ the standard removal capacity test; if achieved, the 95% and 100% breakthrough times ~~should~~ shall also be reported.

**10.2 Air-Cleaner Test Procedure.** This test procedure assumes that, prior to beginning this procedure, the test operator has tested and validated the contaminant generation system and the duct flow system. The test shall be conducted as follows:

- a. ~~Prior to installing the air cleaner for challenge testing, start the test duct and the sampling and analysis systems. Perform routine calibration checks and record the results. Monitor/measure upstream concentrations for all compounds to be analyzed in the challenge test. Establish that the duct background for the challenge gas is below the detection limit or is acceptable, as specified in Section 5.9.~~

- ~~b. Verify that the temperature and RH conditions are at the desired test settings. Start the challenge gas injection into the test rig at one of the two concentrations that will be used. It can be recommended to start with the higher concentration.~~
- ~~c. Once the concentration has stabilized, obtain at least 3 upstream and 3 downstream samples for the no-filter test for each analyzer or pull sample that is to be used in the test, as required in Section 5.9. If these data meet the test specifications as detailed in that section, continue with step (d). Otherwise, perform maintenance or system adjustments until the no filter requirements are met and restart the test. For tests with real time sampling, these data may be used. In studies using non real time sampling techniques (e.g., pull samples), one cannot determine the correlation value (no air cleaner penetration value) at this point. In this case, the previously completed QA test (see Section 5) will be considered sufficient to proceed with the test. However, if these actual test data fail the requirements, the test should be considered out of specification and will need to be repeated.~~
- ~~d. Disconnect the challenge gas injection (feed stream) from the test rig or otherwise redirect the challenge gas so that it does not enter the test section, making sure that the challenge gas is being vented safely.~~
- ~~e. Repeat steps c and d for the other (either low or high) concentration.~~
- ~~f. Purge the test rig in preparation for opening it to insert the test air cleaner. The time required to do this will depend on the test rig setup, but it should not be more than a few minutes. The criterion for completing the purge is to avoid exposure of the test rig operators to excessive concentrations of the challenge gas and to lower the rig concentrations below those required for the initial efficiency test. Following the purge period, stop or slow down the airflow such that the access doors can be opened.~~
- ~~g. Open the doors of the test rig and install the air cleaner. Check to ensure that the installation is leak free for devices intended to seal into the rig. Proper installation ensures that there is no unintended by pass around the air cleaner. Also check to ensure that leaks inherent in the air cleaner housing, as supplied to the test lab, are not sealed. For EAC, be sure the power cord runs through a well sealed opening and is accessible. Be sure the air cleaners can be turned on from outside of the test rig and that they do not have airflow switches that will turn them off during the test when they should be on.~~
- ~~h. Close the door of the test rig. Start the airflow through the air cleaner.~~
- ~~i. Monitor and record the temperature and RH at least 10 times throughout the challenge test. Monitor and record the challenge pressure, the resistance to airflow across the air cleaner, and the ASME flow nozzle (orifice) resistance to airflow at least 2 times during the test.~~
- ~~j. Allow the air cleaner to equilibrate to the test temperature and RH if it has not already been equilibrated during the testing described in Section 9.~~
- ~~k. Perform resistance to airflow curve measurements according to the requirements of Section 9.5 if not performed previously.~~
- ~~l. Using each sampling technique, analyzer, and sampling device, take at least 2 downstream concentration samples to determine if the air cleaner gives off or produces the challenge compound or other by products.~~
- ~~m. Start or reconnect challenge gas injection at the initial removal efficiency (low concentration) level. For EAC, turn on the device. Start the test timer immediately. If using a single analyzer, measure upstream first for 5 minutes, then take downstream measurements continuously for 55 minutes. Then sample upstream for 5 minutes. Downstream measurements shall be taken at equal time intervals. For dual analyzer tests and for sampling device testing, sampling upstream and downstream shall cover 60 minutes. For sampling devices, this may be done as 60 minute samples or as shorter ones. Each sampling technique must be done in at least triplicate. For analyzers, this will be sequential samples and should be approximately 60-65 samples. When using gas sampling devices, this could be, for example, (Qty =) 3 60 minute upstream samples and 3 60 minute downstream samples or 3 sequential 20 minute samples upstream and downstream.~~
- ~~n. For an extended steady state removal efficiency test, continue the low concentration exposure for 4 more hours. If using sampling techniques to determine the concentration of the upstream challenge~~

~~compound, take enough samples to yield concentration curves for upstream and downstream with enough separate samples to allow determination of the removal efficiency at least for every hour increment. Note that the sample analysis must allow determination of the concentration of the challenge gas (simple TVOC measurements are not sufficient). Real time analyzers shall collect samples from both upstream and downstream at least 10 each per hour. At 4 hours, stop the challenge and skip to step r-desorption.~~

- ~~o. For the removal capacity test, stop the low concentration challenge.~~
- ~~p. For the removal capacity test, switch to standard removal capacity concentration generator or generator settings and to required analytical equipment.~~
- ~~q. Start standard removal capacity test challenge gas generation. If necessary, remove the air cleaner while establishing the concentration. If possible, determine settings before the air cleaner is initially installed so that the transition may be smooth and made with the air cleaner in place. Record the start time and all settings.~~
- ~~r. Operate according to Sections 8.1.3 and 8.1.5 (standard challenge test of up to 4 hours or 95% breakthrough if this can be determined during test). For single analyzer systems, monitor downstream concentrations with regular checks on the upstream concentration. The first sample should be downstream. It is acceptable for repeated downstream samples to be taken before switching to upstream, especially if immediate high level breakthrough is anticipated or seen in the data. For dual analyzers, upstream and downstream sampling should occur throughout the test. Pull samples or other non real time sampling shall be done to determine the upstream and downstream concentrations of the challenge compound throughout the 4 hour period. For air cleaners that are known not to produce by-products for the specific challenge compound, measuring with a TVOC device is acceptable if the challenge is VOC. However, if the initial efficiency by products tests come back showing by products, the test will need to be repeated and those by products accounted for. For air cleaners that produce by-products, the measurements must determine the actual concentrations of the specific challenge compound and by products.~~
- ~~S. Stop the contaminant injection and continue the airflow. Continue the desorption run for up to 30 minutes or until the concentration is 10% or less of the test's challenge contaminant concentration. Continue sampling downstream for the desorption portion of the test.~~
- ~~t. Plot the upstream and downstream concentrations for the standard capacity test to define the shape of the break through (if any) and the desorption curves, compared with the challenge concentrations, as in the example shown in Figure 10-1.~~
- ~~u. If testing an EAC, turn off the power.~~
- ~~v. Record the final air cleaner resistance to airflow.~~
- ~~w. Turn off the test rig and remove the air cleaner. If the downstream concentration exceeds acceptable levels for operator safety, it is recommended that airflow be continued through the air cleaner until the challenge gas is safely vented before removal.~~

**10.32 Concentration Plot.** The upstream and downstream concentration data for the standard capacity test against elapsed time shall be plotted on the same graph as shown in Figure 10-1. A similar graph may be prepared for the initial efficiency test if there are sufficient data points to allow it. The desorption portion of the graph provides a way to approximate the retentivity for comparison purposes between air cleaners. Include concentrations of all compounds that were found in the analyses. One graph may be done for all compounds or separate graphs for subsets of the compounds.

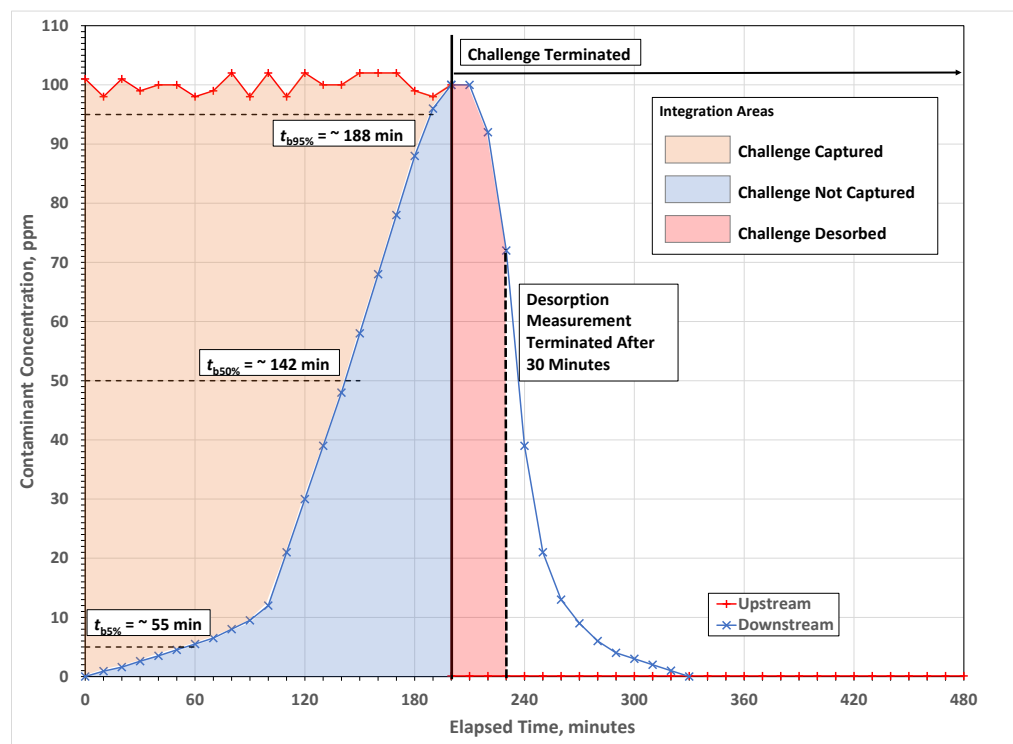


FIGURE 10-1 Example of a concentration plot showing the challenge and off-gassing desorption periods. The regions integrated to compute media capacity and retentivity are shown, along with the breakthrough times. This plot is fairly typical of adsorbent-based air cleaners.

**10.43 Initial Removal Efficiency Test, Penetration,  $P_0$  (%)**. Compute the penetration for the low-concentration, initial efficiency test using Equation 10-1.

$$P_0 = \left( \frac{C_o}{C_i} \right) \times 100 \quad (10-1)$$

where

$C_i$  = inlet (air cleaner upstream challenge) gas concentration (in  $\mu\text{g}/\text{m}^3$  ppb) averaged over the challenge portion of the test

$C_o$  = outlet (air cleaner downstream challenge) gas concentration (in  $\mu\text{g}/\text{m}^3$  ppb) averaged over the time specified in Section 8.2

**10.54 Initial Removal Efficiency Test, Removal Efficiency,  $E_0$  (%)**. Compute the initial removal efficiency using Equation 10-2.

$$E_0 = (100 - P_0) \quad (10-2)$$

**10.6 Initial Efficiency Test Corrected Removal Penetration,  $P_c$  (%)**. Compute the corrected penetration for the low-concentration, initial efficiency test using Equation 10-3.

$$P_c = \frac{(C_o + C_b)}{C_i} \times 100 \quad (10-3)$$

~~$C_b$  = the sum of the concentrations of by-product compounds (in ppb) found at the outlet including ozone unless it is an ozone challenge test where the ozone is included in  $C_o$ .~~

**10.7 Initial Efficiency Test Corrected Removal Efficiency,  $E_e$  (%).**

Compute the Initial Efficiency Test Corrected Removal Efficiency using Equation 10-4.

$$E_e = (100 - P_e) \quad (10-4)$$

**10.85 By-product Production Percentage (BPP).**

Calculate BPP using Equation 10-5.

$$BPP = \frac{C_b}{C_i} * 100 \quad (10-5)$$

where

$C_b$  = the sum of the concentrations of by-product compounds (in  $\mu\text{g}/\text{m}^3$ ) found at the outlet including ozone unless it is an ozone challenge test where the ozone is included in  $C_o$ .

**10.96 Report  $C_b$ .** Tabulate the actual concentrations for all by-products. In addition to this, report a total of these concentrations as a by-product level.

**10.107 Extended Steady-State Removal Efficiency Test.** For each hour of the extended steady-state removal efficiency test, report the same data and calculated values as done for the Initial Efficiency Test. If the removal efficiency values for the Steady-State test remain the same (i.e., no degradation in performance compared to the first 60 min.), report that “the air cleaner retained its efficiency throughout the steady-state test.” The removal efficiency is considered the same if none of the computed steady-state removal efficiencies over the 4-hour extended test period fall below 90% of the initial efficiency test removal efficiency. For example, an air cleaner with an initial efficiency test removal efficiency of 50% may not drop below 45% during the 4-hour extended test period.

**10.118 Standard Removal Capacity Test, Penetration,  $P_t$  (%).** Compute the penetration for each time interval using Equation 10-1.

Where

$C_i$  = inlet (air cleaner upstream challenge) gas concentration (in ppm) averaged over the challenge portion of the test

$C_o$  = outlet (air cleaner downstream challenge) gas concentration (in ppm) at time,  $t$ .

Because rig background concentrations will be insignificant, background corrections are not required for this test. Plot the penetration versus elapsed challenge time (beyond the conditioning period). However, in the case that a non-real time sample shows low concentration (<10 ppb) of a compound, the test concentrations determined with the challenge gas compound on may be adjusted by these background levels as it will be impossible to determine corrections at the time of the test.

**10.129 Standard Removal Capacity Test, Removal Efficiency,  $E_t$  (%).** Compute the removal efficiency for each time interval during the challenge period using Equation 10-6.

$$E_t = (100 - P_t) \quad (10-6)$$

Plot the efficiency versus elapsed challenge time (beyond the conditioning period). The value for the efficiency at the end of the test shall be computed using Equation 10-6 and reported in the test report.

**10.1310 Capacity for Removal,  $C_R$  (mass).** Because the breakthrough levels for different air cleaners may vary, yielding different data sets, the capacity for removal should be reported as appropriate for the test, see below. For those tests where 100% breakthrough is reached, the  $C_{R95+00}$  should be reported. For those tests that do not reach 100% breakthrough, the  $C_{R4h}$  should be reported. Additional capacities for removal may be calculated following the same procedure if the data permit.

Compute the incremental capacities ( $C_{R_t}$ ) for removal for each time interval during the challenge period and then compute the total (integrated) capacity to a specific fractional breakthrough ( $C_{R_x}$ ) by summing the incremental mass collected components across all time intervals as shown in Equation 10-7 for a 95% breakthrough.

$$C_{R_{95}} = \frac{Q \sum_{n=1}^N (C_{i_t} - C_{o_t})(MW)(28.317)(t)}{(10^6)(24.414)} g \quad (10-7)$$

where

- $N$  = total number of time intervals since test startup to 95% breakthrough
- $t$  = length of interval, min
- $C_{i_t}$  = inlet challenge gas compound concentration (in ppm) for the interval
- $C_{o_t}$  = outlet (media downstream) gas challenge compound concentration (in ppm) at time,  $t$
- MW = molecular weight of challenge compound gas
- $Q$  = airflow rate for the test, cfm

Capacities to additional breakthrough percentages may be calculated by the same procedure using the data for the increments up to the desired breakthrough time. ~~The capacity to 5% ( $C_{R_5}$ ) may be difficult to determine accurately for media with low capacities and short breakthrough times but should be calculated if possible. Likewise,  $C_{R_{95}}$  should be calculated if the test reached this breakthrough percentage. The 5% ( $C_{R_5}$ ) and 50% ( $C_{R_{50}}$ ) capacities are required to be determined for this method if the breakthrough reaches these levels or higher. For devices where the breakthrough did not change (increase or decrease more than 5%), the capacity value shall be marked as “maintained efficiency.”~~

**10.1411 Other Parameters.** The mean challenge concentration, penetration, removal efficiency, and removal capacity during the challenge period ( $T_C$ ) may be computed as simple averages over the  $N$  time intervals.

## 11. REPORTING RESULTS

**11.1** The test report shall contain at least the following information.

### 11.1.1 General Data

- a. Date of test
- b. Test lab and technician performing the test
- c. Unambiguous identification of test air cleaner
- d. Brief narrative description of selection procedure used for air cleaner samples tested

- e. Test conditions, including challenge flow rate, temperature, RH, residence time, and preconditioning time.
- f. Gas analyzers descriptions, and/or sampling method descriptions, including detection limits

#### **11.1.2 Initial Removal Efficiency Test Results**

- a. Challenge ~~compound~~gas
- b. Challenge ~~gas~~compound concentration (average)
- c. Resistance to airflow across the equilibrated air cleaner in Pa (in. of water)
- d. Average removal efficiency and penetration values
- e. By-product individual concentrations and total concentration
- f. By-product production percentage
- ~~g. Corrected efficiency and penetration values~~
- ~~h. Ozone concentration downstream~~
- ~~i. Challenge airstream total flow rate~~
- i. Table of upstream and downstream concentrations of the challenge compound versus time

#### **11.1.3 Extended Steady-State Test Results**

- a. Average removal efficiencies for at least each hour
- b. Table of concentrations for all compounds (challenge and by-products) upstream and downstream
- c. Statement about removal efficiency stability, if earned

#### **11.1.4 Removal Capacity Test Results**

- a. Challenge ~~gas~~compound concentration
- b. Total challenge and desorption times in minutes
- c. Final resistance to airflow across the ~~equilibrated~~ air cleaner in Pa (in. of water)
- d. Time to reach Removal Efficiency breakthroughs of 5%, 50%, 95%, and 100% if achieved
- e. Removal Capacity at 4 hours or 95% breakthrough shall be included
- f. Challenge airstream total flow rate
- g. Upstream/downstream concentration table and curves (graphical) versus time

#### **11.1.5 Supporting Parameter Results**

- a. ~~Pressure drop~~ Resistance to airflow across the air-cleaner data—Pa (in. of water) versus flow rate
- b. Challenge temperature and RH during the equilibration period and test

**11.2 Test Report.** All required test results shall be included in a comprehensive ASHRAE Standard 145.2 Gas-Phase Air-Cleaning Device Performance Report such as the one included in Appendix D ~~after the references (Section 13)~~. This test report is an example of an acceptable report format. The exact formats shown in the example report are not required, but the report shall include all of the items shown. An example completed test report (summary only) is included as Figures D-1 and D-2 in Appendix D.

## **12. SAFETY AND ENVIRONMENTAL IMPACT**

**12.1 Lab Safety.** Standard safety precautions should be followed for general laboratory safety.

### **12.2 Fire and Explosion Hazard**

**12.2.1 Fire and Explosion Hazard Due to Sorptive/Reactive Effects.** Many test chemicals are flammable, and some are explosion hazards. The operator must check the material safety data sheets (MSDSs) for any chemical used in order to ensure an explosive or fire hazard is not present.

In some modes of operation, a protective filter bed can reach very high temperatures and possibly ignite. Care should be taken when running any new conditions to ensure that a fire hazard is not present. The risk of fire increases for some chemical/sorbent combinations when higher chemical concentration challenges are used. When increasing the challenge concentration in a test, the operator must take care not to cause a large increase in bed temperature. Very reactive chemicals have been known to cause bed ignition due to the high rate of reactivity.

**12.2.2 Fire and Explosion Hazard During Liquid Chemical Vaporization.** Depending on the test chemical, concentration, and flow rate, vaporization of liquid chemicals may pose a flammability or explosion hazard. An 850 cmh (500 cfm) test at 1000 mg/m<sup>3</sup> requires a liquid feed rate approaching 1 L/h (0.264 gph). Heating will normally be required. If the chemical is flammable, vaporization must be performed with care to ensure that a fire does not occur.

Vaporization in an inert atmosphere is recommended for flammable chemicals. An approach that has been successful is to use a positive feed device (syringe pump or small pump) to inject the chemical at the needed rate into a packed vaporization bed through which a heated inert gas is flowing. The chemical vaporizes into the inert gas and is then injected into the test apparatus through a gas distribution system, ensuring its rapid dilution below the explosive limit.

Whatever the vaporization system used, the heaters and pumps should be interlocked to prevent chemical injection in case of a loss of carrier gas pressure, electricity, or duct flow, or in case of any other abnormal operating mode that might create a hazard. Pressure relief should be utilized if the system cannot relieve itself of excessive pressure. The equipment should be purged thoroughly before shutting it down so that all chemicals in the system are vaporized and vented.

**12.3 Toxicity of Challenge CompoundsGases.** The issues of challenge ~~gas~~compound toxicity are discussed both in the Foreword and Section 5, primarily in regard to minimizing operator exposure to concentration

levels that might exceed the PELs. In order to maximize the level of safety, inhalation risks must be minimized by conducting a relatively simple and quick tracer leak test prior to each challenge in order to demonstrate that work area concentrations will be acceptable to the test organization's safety and health management organization. This test method does not recommend allowable concentrations or exposures.

While the most expedient safety device to minimize operator exposures is to apply appropriate exhaust ventilation shrouding around the test apparatus to capture any inadvertent challenge ~~contaminant~~compound leaks, the physical size of the largescale test apparatus will limit the utility of this option in most cases. The design of the exhaust system should meet appropriate ASHRAE requirements. This procedure may be used with toxic chemicals. All components of the process should be located within a well-ventilated area. The operator must wear appropriate personal protective equipment. The operator must read and understand MSDSs associated with the chemicals employed by the process and the materials that compose the filter bed. The operator is expected to be familiar with the operation of the test apparatus and to have read and understood this method.

The evaluation of chemical toxicity issues must include consideration of the effects of leaks or spills on the test operator and nearby personnel. Particularly at full scale, large quantities of chemicals may be required,



and the effects of leaks and spills may be substantial. Storage and handling standard operating procedures must be developed and followed, if not already in place.

**12.4 UV and Ozone.** Be sure to find out the safety requirements for use of the specific air cleaners that are being tested. Follow manufacturer's warnings and good lab practices concerning exposure to UVC light and to ozone.

**12.5 Other Safety Issues.** Other safety or health-related issues are ~~compound~~ ~~contaminant~~ and air-cleaner specific. Individual laboratory standard operating procedures should be followed for dealing with these issues.

**12.6 Environmental Impact.** The challenge ~~gases~~ ~~compounds~~ used in this standard's test method may be periodically vented to either a local exhaust scrubbing system or to the building roof exhaust system for release to the atmosphere. The low total quantity of ~~contaminant~~ suggests that for some compounds at some concentrations, both alternatives may be viable, depending on local requirements. However, it is important to note that the total flow of contaminated air will be relatively high. These releases under normal situations (non-catastrophic) will occur primarily from the locations shown in Figure 5-1 as "vent." The allowable ~~compound~~ ~~contaminant~~ concentrations and flow rates will be governed by the prevailing institutional and local government requirements on releases to the atmosphere.

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ASHRAE Std 145.2-2022 Gas-Phase Air Cleaner Performance Report (This report applies only to the device tested.)			
<b>Laboratory Data</b>			
Report Number		Date	
Test Laboratory		Supervisor	
		Operator	
Sampling Techniques			
<b>Analyzer Details</b>			
Contaminant	Model	Technique	Detection Limit
<b>Pull Sample / Analytical Methods</b>			
Contaminants	Method	Technique	Detection Limit

<b>Device Manufacturer's Data</b>			
Manufacturer		Test Requested by	
Product Name		Sample Obtained from	
Product Model		Serial Number	
Catalog Rating		Rated Airflow	
Initial resistance to airflow		Rated Face Velocity	
Final resistance to airflow		Residence Time	
<b>Device Description</b>			
Nominal Dimensions		Physical Description	
Technologies		Other	
<b>Test Conditions</b>			
Test Type (Extended steady state efficiency or Capacity):			
Challenge Gas/Conc.		Airflow	
Temperature		Face Velocity	
RH		Final Resistance to Airflow	
Preconditioning Time		Preconditioning T/RH (final)	
Remarks			
<b>Resistance to Airflow Test</b>			
Airflow (cfm)	Resistance to Airflow (in. w.g.)	Airflow (cfm)	Resistance to Airflow (in. w.g.)

ASHRAE Std 145.2-2022 Gas-Phase Air Cleaner Performance Report (This report applies only to the device tested.)			
<b>Initial Removal Efficiency Test Results</b>			
Challenge Gas		By-product(s) Conc., Individual and Total	
Upstream Conc.		Chemical	Concentration (ppb $\mu$ g/m <sup>3</sup> )
Pressure drop Resistance to Airflow			
Average Removal Efficiency (%)			

Average Penetration		total	
Challenge Gas Correlation		BPP (%)	
Average Corrected Removal Efficiency (%)		BPP (%)	
Average Corrected Penetration			
<b>Extended Steady State Test Results</b>			
Time (hr)	Corrected Removal Efficiency (%)		
Removal Efficiency Stability Statement, if earned			
<b>Removal Capacity Test Results</b>			
Upstream Cone		Total Challenge Time	
Final Resistance to Airflow Pressure Drop		Capacity	
Removal Efficiency			
Removal Efficiency			
Notes			
Desorption Time			

ASHRAE Std 145.2-2022 Gas-Phase Air Cleaner Performance Report (This report applies only to the device tested.)				
<b>Initial Removal Efficiency Test Tabulated Results</b>				
Time	Upstream Cone.	Downstream Cone.	Removal Efficiency	Penetration

ASHRAE Std 145.2-2022 Gas-Phase Air Cleaner Performance Report (This report applies only to the device tested.)				
<b>Extended Steady State or Removal Capacity Test Tabulated Results</b>				
Time	Upstream Cone	Downstream Cone	Removal Efficiency	Capacity

**(This is a normative appendix and is part of the standard.)**

## **NORMATIVE APPENDIX A**

### **LARGE-SCALE TEST DUCT—LEAK CHARACTERIZATION AND CONTROL**

#### **A1. SUMMARY**

The goal of test duct leak evaluation and control is to reduce and control operator exposure to potentially harmful materials. This appendix provides guidance on reducing the hazards associated with inadvertent test duct leaks. A complete testing safety program must be much broader than what is covered by the material in this appendix and must also consider, for example, toxic and flammable material handling, challenge compound~~contaminant~~ gas generation, procedures for duct access, and disposal of air clean-up filters. Test ducts differ in design, construction, ventilation of the containing building, and operating procedures. From the guidance provided in this appendix and from other sources, each test duct operator must develop a customized leak evaluation and control procedure as part of its safety plan.

This appendix provides leak test guidance for using an inert gas to simulate the in-duct challenge concentration levels under defined operating flow rate, resistance to airflow, temperature, and RH conditions. The tracer levels are then monitored outside the duct in the operator areas to estimate expected concentrations and allow the test organization to determine whether safe operating levels have been reached. If excessive work area concentrations are measured, a leak detector must be used in a snoop mode to identify specific offending leaks for correction.

#### **A2. BACKGROUND**

**A2.1 Overview.** The test method in this standard is specifically written to allow the modification of ASHRAE Standard 52.2<sup>4</sup> test ducts for gaseous air-cleaning device testing. Standard 52.2 test ducts are typically operated at above atmospheric pressure because leakage of the low concentrations of inert particles out of the duct are not hazardous, so in-leakage of ambient particles merely pose a risk of measurement errors. Standard 52.2 requires that leakage be less than 1% of the total challenge airflow. For gaseous challenge compound~~contaminant~~ tests conducted at approximately the 100 ppm concentration level, however, the situation in some cases is reversed. Out-leakage might be hazardous while in-leakage might have little effect. This appendix was written to give safety guidance to full-scale test duct operators with emphasis on those who are converting Standard 52.2 ducts from particle to gaseous-device testing.

**A2.2 Example of Leakage from an ASHRAE Standard 52.2 Duct.** A 17 cmh (10 cfm, 1% of 1000 cfm) leak of test duct challenge air containing 100 ppm of SO<sub>2</sub> would require substantial dilution to reach the long-term PEL. The impact of that leakage on worker safety would depend on where the leak was and the local ventilation rate. Local laboratory safety requirements might well impose an additional safety factor and require more dilution. Achieving these levels of dilution in the entire workspace around a test duct in a conditioned laboratory is technically challenging and expensive. Leak reduction is desirable to reduce both the potential hazard and the ventilation requirements.

Figure A-1 shows leak rates as a function of test duct pressure for a particular Standard 52.2<sup>4</sup> test duct test section. The two lines show the static leakage rate for the test section, measured in the manner required by Standard 52.2, before and after a leak sealing effort. Though the leak rates shown in Figure A-1 are for the test section only, the leak reduction program was applied to the entire duct. Between the two measurements, a concerted effort was made to identify and characterize all of the leak points in the apparatus. Soap-bubble testing was used to identify 40 leak points. These included access door gaskets, diverter louvers, test probe caps, flexible duct seals, and flange seals—roughly in decreasing order of importance. An important

“leakage” source was found to be inadvertently uncapped Standard 52.2 test probes. These leaks were sealed using a combination of tubing caps, low-emitting gaskets, caulk, and conformal sealants. As Figure A-1 shows, the sealing efforts reduced leakage but by no means eliminated it.

### A3. LEAK EVALUATION AND CONTROL GUIDANCE

**A3.1 General Approach to Leak Evaluation and Control.** The general approach recommended is as follows:

- a. Minimize the overall duct leak rate through a detailed inspection, soap-bubble testing gaskets, and sealing as appropriate before the start of testing and whenever any duct alterations are made.
- b. Characterize the duct leak rate using the Standard 52.2<sup>4</sup> leak test procedure. The test duct shall meet the Standard 52.2 leak criteria before proceeding.
- c. Operating the duct at the desired flow rate, temperature, and RH, utilize appropriate flow restrictions to raise the pressure in the test duct to at least 750 Pa (3 in. of water). Inject a nontoxic and inert tracer gas into the test duct and, using a real-time gas detector, scan flanges and doors to ensure they are properly sealed. Ensure that the laboratory ventilation system is operating in its normal operating mode. Measure the tracer concentration in the operator workspace and account for any background level if required. Several replicate measurements may be required to ensure that a steady-state concentration has been reached.
- D. Calculate a dilution factor for the operator workspaces as work space concentration divided by test duct concentration.
- e. For any challenge chemical, the estimated workspace concentration is the dilution factor times the challenge concentration. If that concentration exceeds safe limits provided in the test organization safety plan, corrective action is required.

**A3.2 Example Dilution Factor Determination.** A large-scale test duct operating at 25°C (77°F), 50% rh, and at 1700 cmh (1000 cfm) was operated for 30 minutes to ensure it was at a stable operation condition. A combination of a HEPA filter and a perforated plate had been installed in the test section to provide a positive duct pressure of 750 Pa (3.0 in. of water) at the test section. A commercial compressed gas cylinder of 99.9% pure helium was then metered through a regulator and calibrated rotameter into the duct at a rate that gave an in-duct concentration of approximately 1870 ppm. A calibrated analyzer was used to verify the in-duct concentration level. Tracer gas from the duct leaked into the operator area, reaching an equilibrium concentration of 1.6 ppm—well above the analyzer detection limit of about 0.1 ppm. The wide dynamic range of this analyzer allowed it to be used to confirm both the in-duct concentration level and the much lower operator workspace concentration. After terminating the tracer gas injection, the operator workspace concentration was monitored with the analyzer and found to decrease exponentially to background.

The dilution ratio for the tracer gas was determined to be 1170 (1870 ppm/1.6 ppm.) Assuming that the same ratio could be expected from any challenge gas-compound leaking into operator working space, expected operator area concentrations can be computed. For 100 ppm challenges of SO<sub>2</sub>, the expected operator area concentration would be 0.09 ppm (100 ppm/1170). This expected level would be well below the OSHA permissible exposure limit (PEL) for SO<sub>2</sub> of 5 ppm. The low expected operator space concentration, coupled with the earlier scan for gas leaks, indicates that operation under the proposed conditions is probably safe.

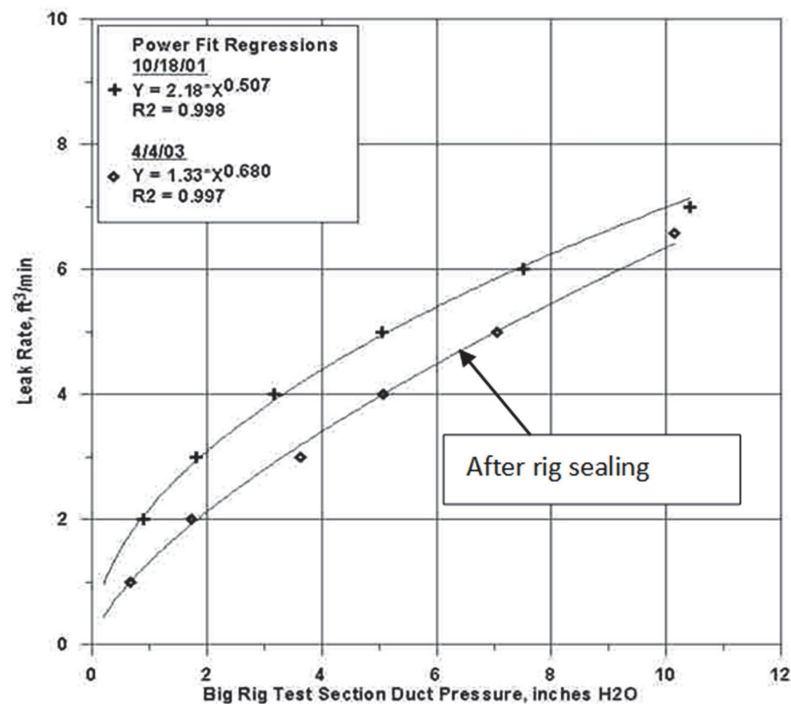


FIGURE A-1 Static leak test of ASHRAE Standard 52.2 duct.

**A3.3 Daily Test Duct Leak Check.** The frequency with which the routine duct leak check must be conducted will depend on the test duct design and the operating procedure. The recommended approach is to begin testing on a daily basis and to adjust the leak check frequency based on the leakage history for the apparatus until it becomes defined, especially for routine operations such as access door openings and resealing.

The procedural guidance below assumes that a Standard 52.2 leak test has been conducted and that the expected routine leak characterization test includes at least the following steps:

- Determine the background tracer concentration level adjacent to the apparatus and determine if any previously unidentified tracer sources in the facility (e.g., from leaking gas chromatographs) might compromise the leak test.
- Operate the rig with the air conditioned to 25°C (77°F) and 50% rh and with a simulated test obstacle (e.g., perforated panel or blanking filter) in place of the test cartridge to provide a representative upper-limit pressure within the ducting at the nominal 1700 cmh (1000 cfm) flow rate (set at 750 Pa [3.0 ± 0.5 in. of water]).
- Continuously inject a known rate of tracer into the test rig at the normal, upstream injection point to provide a well-mixed concentration approximating the desired working concentration—in this case, 200 ppm at a flow rate of 1700 cmh (1000 cfm).
- Initially monitor the tracer level inside the ducting at a downstream, well-mixed location for 5 minutes to verify that the computed injection rate is producing the desired in-duct concentration.
- Reset the analyzer scale (if necessary) and move the monitor probe to a location outside the ducting representing the air most likely to be breathed by the rig operators (see Figure 3-1) external to the ducting.



- f. If the monitored equilibrium concentration measurements outside the ducting are below the analyzer limit of detection (LOD) or above the optimal range for the tracer analyzer, alter the tracer injection rate into the ducting until a readable and relatively stable equilibrium level is attained, repeating Steps (d) and I.
- g. When the externally measured concentration has maintained an equilibrium level for 5 minutes, compute the level of reduction observed in concentration inside the ducting, compared with the operator area equilibrium concentration outside the ducting.
- h. If the operator area equilibrium levels are high (by more than 50%) relative to previously conducted tests, terminate the routine leak characterization, and utilize the monitor probe in a portable snoop mode to identify the high emission points and determine how it can be sealed and the testing repeated.
- i. If the operator area equilibrium levels are normal (within  $\pm 20\%$  of previous tests for the same room ventilation characteristics<sup>†</sup>), compute the expected SO<sub>2</sub>, NH<sub>3</sub>, and DMMP concentration levels and compare them with the appropriate health-based target PELs.
- j. Determine whether the leak rate is acceptable based on the PELs to conduct the planned sorptive testing.
- k. Terminate the tracer injection, track the rate of concentration decrease in the facility, and determine from the estimated air exchange rate whether the facility ventilation system is fully operational.
- l. Complete a system leak characterization summary form to be appended to the data report for the sorptive test as part of the system qualification testing, and file with the test rig system records to provide comparison data for future tests.

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<sup>†</sup> The equilibrium operator area concentration is dependent on several factors, most important of which is the overall air exchange rate induced by the facility ventilation system. For most commercial HVAC systems, this will be reasonably consistent from day to day. However, the operation of other ventilation applications in the vicinity (such as turning on fume hoods) may alter the overall AER and in turn alter the equilibrium concentration observed for a given tracer injection rate.

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**A3.4 Checklists.** Due to the critical importance of conducting a valid leak characterization prior to conducting an actual challenge test, checklists are needed to assure that key steps are taken prior to and during the leak characterization. If the large-scale rig is alternatively used for Standard 52.2 testing, steps must be taken in converting the rig to the Standard 145.2 format. These steps include converting the flow system from recirculating to once-through mode and capping all potential openings. These steps are itemized in Table A-1. The rig must then be set up for Standard 145.2 operation as described by the steps in Table A-2. Then the leak test apparatus (injection system and leak test analyzer) must be set up properly as described in Table A-3. These checklists should be completed prior to every test.

**A3.5 Data Sheets.** The data sheet to record the large-scale rig operating conditions during the test, the in-duct helium concentrations, and the resultant work area (room) concentrations is shown in Tables A-4 and Table A-5. At the conclusion of the leak characterization testing, stop the flow of helium into the ducting and continue to monitor the room concentration every 2 minutes in Table A-6 until an exponential reduction trend can be plotted.

**A3.6 Leak Characterization Computations.** Using the data from Tables A-4 and A-5, complete the computations as shown in Table A-7.

**A3.7 Room Ventilation (Air Exchange Rate, AER) Characterization.** The exponential reduction in work area (room) helium concentrations, observed and recorded in Table A-6 when the helium duct injections are terminated, can be used to estimate the work area AER. A sequence of these AER

computations will help establish whether the room ventilation system functions normally during the leak characterization test.

The general equation relating concentration as a function of time to AER is given by the following equation:

$$C_t = C_0 e^{-kt} \quad (\text{A-1})$$

where

$k$  = AER in minutes<sup>-1</sup> if units for  $t$  are minutes, or multiply AER by 60 for units of hours<sup>-1</sup>

$C_0$  = initial room concentration at termination of helium injection, ppm

$C_t$  = room concentration at time  $t$  since injection termination, ppm

Alternatively, Equation A-1 can be:

$$k = (1 / t) \ln[C_0 / C_t]$$

Utilize any available fitting software to fit data in the exponential form of Equation A-1 to determine the exponent  $k$  from which the AER is computed. An example graph is plotted in Figure A-1 showing the exponential concentration decrease.

**A3.8 Duct Mixing.** To ensure a well-mixed concentration, the helium is injected just ahead of the upstream mixing disc at the standard injection location for Standard 52.2 <sup>4</sup> and measured at a downstream location (relative to the test cartridge position) just downstream of a second mixing disc and at the standard downstream monitoring location. To avoid the turbulence interference at the entry of the upstream and downstream probes, the gas injection and sampling probes are offset downstream by 5 cm (2 in.). Uniformity testing across the duct shows no measurable biases across the duct at all locations at least 25 mm (1 in.) from the wall.

**A3.9 Duct Operating Conditions.** All access doors and test ports not required for gas-phase testing are to be checked and closed if opened during previous (e.g., Standard 52.2 4) testing. This includes capping isokinetic sampling nozzles to prevent backflow external to the ducting. Because the normal operating mode for gas-phase testing is once-through operation, this mode is established by closing the necessary interior baffles.

The duct air temperature was then set to 25°C (77°F) and 50% rh at a flowrate of 1700 cmh (1000 cfm). These conditioned were established for 30 minutes to allow all interior duct wetted surfaces to equilibrate to these settings.

### Check-Off Tables for Large-Scale Rig Dynamic Leak Characterization Operator Test ID Date

**TABLE A-1 Rig Changeover Checklist: From Standard 52.2 Particle Penetration Test to Standard 145.2 Gas-Phase Test**

#	Description	Done? ✓	Comments
1	Fan OFF?		
2	52.2 generator disconnected?		
3	52.2 generator pipe capped?		
4	52.2 upstream and downstream nozzles capped?		Use cap-plugs
5	145.2 upstream and downstream nozzles installed?		

6	145.2 nozzles uncapped?		
7	Once-through diverter plate installed?		Close damper first
8	Intake/exhaust dampers properly positioned?		
9	52.2 test media removed?		
10	All unused external test ports plugged?		
11	All unused external doors fully and uniformly closed?		
12			

**TABLE A-2 Large Scale Rig Setup**

#	Description	Done? ✓	Comments
1	Fan OFF?		
2	Perforated plate (dummy pressure load) installed?		
3	Downstream cleanup cartridges installed?		
4	Appropriate ASME flow nozzle installed?		
5	Flow nozzle pressure sensor functional?		
6	52.2 test section leak test conducted within 12 months?		
7	HOBO reset and placed upstream of injection point?		
8	Fan ON and set to 1000 cfm(1700 cmh)		
9	Temperature (25°C/77°F) and RH (50%) stabilized?		
10	Total/differential duct pressure sensors functional?		
11			

**TABLE A-3 Leak Test Apparatus Setup**

#	Description	Done? ✓	Comments
1	Sufficient helium in tank (~300 psi [~2070 kPa]) to conduct test?		
2	Helium flowmeter calibration on file?		
3	Leak detector allowed to warm up for 15 minutes?		
4	Leak detector internal calibration conducted?		
5	Leak detector multipoint calibration on file?		
6	Leak detector span check conducted?		
7			

**A3.10 Resistance to Airflow Development.** The desired elevated resistance to airflow in the test section of 3 in. of water was arbitrarily selected to be representative of an upper-end pressure for these tests. To limit the potential for excessive leakage of the potentially toxic gases into the operator work area, the pressure level should not exceed 3.75 kPa (5 in. of water). A 2.25 kPa (3 in. of water) level can be obtained by a combination of HEPA filter elements and/or a properly sized perforated wooden panel at the air-cleaner test point. An electronic differential manometer is used to monitor the duct pressure upstream of the test

point, relative to that of the room. A differential manometer is used to monitor the resistance to airflow across the standard ASME flow nozzle used to monitor the 1700 cmh (1000 cfm) flow rate.

**A3.11 Estimation of Air Exchange Rate.** The ventilation rate in the high bay facility housing the large-scale test rig was assessed from the rate that the room helium concentrations decreased when the duct injections were terminated. The data in Figure A-2 shows the exponential decrease. An air exchange rate (AER) of 12 hours<sup>-1</sup> was computed from the fitted regression data. The normal AER in this facility is quite large (8 to 10 hours<sup>-1</sup> is made even higher by having the apparatus in the once-through mode and exhausting 1700 cmh [1000 cfm] of room air to the outside during normal operation).

**TABLE A-4 Data Sheet for Large-Scale Rig Dynamic Leak Characterization**

---

Date: \_\_\_\_\_ Test ID \_\_\_\_\_ Operator \_\_\_\_\_

Check-Off Tables A-1, A-2, and A-3 completed?: Y/N

Lab Temperature:	_____	°C/°F	Barometric Pressure	_____	mm Hg
Test Start Time:	_____	h			
Orifice Pressure Drop:	_____	Pa/in. of water	Duct Flow Rate:	_____	cmh/cfm
Duct Temperature:	_____	°C/°F	Duct RH:	_____	%
Test End Time:	_____	h			
Orifice Pressure Drop:	_____	Pa/in. of water	Duct Flow Rate:	_____	cmh/cfm
Duct Temperature:	_____	°C/°F	Duct RH:	_____	%

**Average Test Conditions**

Duct Flow Rate: \_\_\_\_\_ cmh/cfm [A]    Temperature: \_\_\_\_\_ °C/°F [B]    RH: \_\_\_\_\_ % [C]

Target He duct concentration: \_\_\_\_\_ ppmv    He (pure) injection rate: \_\_\_\_\_

Measured initial He duct concentrations (by ASM110): \_\_\_\_\_ ppmv

Measured final He duct concentrations (by ASM110): \_\_\_\_\_ ppmv

Average initial and final in-duct He concentration (by ASM110): \_\_\_\_\_ ppmv

---

**TABLE A-5 Work Area (Room) Equilibrium Concentrations—Duct Injection ON**

#	time, min	He, ppmv	#	time, min	He, ppmv	#	time, min	He, ppmv
1			7			13		
2			8			14		
3			9			15		
4			10			16		
5			11			17		
6			12			18		

**TABLE A-6 Work Area (Room) Concentration Decay (for Air Exchange Rate [AER] Estimation) Duct Injection OFF**

#	time, min	He, ppmv	#	time, min	He, ppmv	#	time, min	He, ppmv
1			7			13		
2			8			14		
3			9			15		
4			10			16		
5			11			17		
6			12			18		

**TABLE A-7 Computations Sheet for Large-Scale Rig Dynamic Leak Characterization**

Average in-duct conditions (from Table A-4):

Duct Flow Rate: \_\_\_\_\_ cfm [A]      Temp: \_\_\_\_\_ C [B]      RH: \_\_\_\_\_ % [C]

Average Equilibrium He in-duct conc.,  $C_{He_{in}}$  (from Table A-4): \_\_\_\_\_ ppmv [D]

Average Equilibrium He in-duct conc.,  $C_{He_{wa}}$  (from Table A-5): \_\_\_\_\_ ppmv [E]

Ratio 1 ( $R_1$ ) of in-duct He to work area He average

concentrations: ( $[D]/[E]$ ):  $R_1 = ( \text{_____} / \text{_____} ) = [F]$ , unitless

Challenge Gas:  SO<sub>2</sub>       NH<sub>3</sub>       DMMP

Expected work area challenge concentration ( $C_{ch_{wa}}$ ) from 100 ppm in-duct challenge: 100 ppm / [F]:

$$C_{ch_{wa}} = (100 \text{ ppm} / \text{_____}) = [G]$$

Permissible Exposure Limit (PEL) for challenge (see Table 2-1):

Select:  $PEL_{SO_2}$  (5 ppm) ;  $PEL_{NH_3}$  (50 ppm) ;  $PEL_{DMMP}$  (5\* ppm) ;  $-\{H\}$

Is expected work area challenge concentration < PEL?  YES  NO (abort challenge testing)

Ratio 2 ( $R_2$ ) of challenge PEL to expected work area challenge concentration: ( $[H] / [G]$ ):

$$R_2 = ( \text{_____} / \text{_____} ) = [J]$$

Is expected work area challenge concentration less than PEL by an acceptable safety factor of 3?

[J]  $\geq 3$ ,  YES  $\rightarrow$  safe to proceed with challenge testing

[if NO  , reduce leak rate, and redo leak characterization test ]

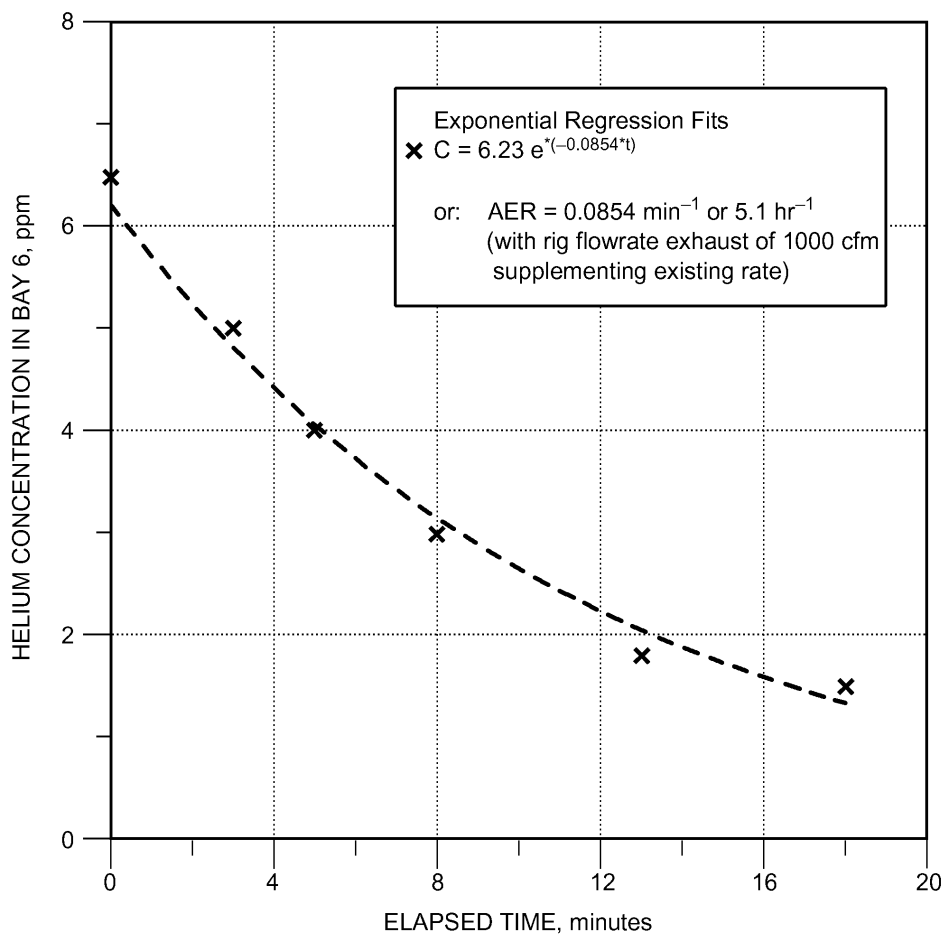


Figure A-2 Example exponential concentration decay in laboratory containing test duct.

**(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)**

## **INFORMATIVE APPENDIX B COMMENTARY ON THE ASHRAE STANDARD 145.2 TEST METHOD**

Air-cleaning devices used in gas-phase air filtration exhibit a wide range of constructions and physical and chemical properties, causing them to be more or less effective against their target compoundsecontaminants. Environmental conditions such as temperature and RH can also contribute to the effectiveness of a system. This test method provides a controlled laboratory test to determine removal efficiencies and capacities of individual air-cleaning devices. This procedure does not necessarily give the results that would occur under specific operating conditions. It does, however, allow comparisons (rankings) of different devices and can be a useful quality control method for new devices.

With high-performance gas-phase air-cleaning devices, low-level (ambient) gas concentration challenge testing usually takes long periods of time to obtain meaningful data. Therefore, this procedure combines initial low-level efficiency tests with accelerated challenge testing to determine the removal capacities of various devices by exposing them to high levels of challenge compoundsecontaminants.

Air-cleaning devices can be used in different locations in a ventilation system (in the recirculating air, outdoor air, or supply air), and the media can thus be exposed to a variety of airflows, temperatures, humidities, and mixtures of compoundsecontaminants. To enable devices to be compared meaningfully, some standard/typical sets of conditions need to be selected for the tests.

Air cleaners containing gas-phase control media are used for a variety of different applications, and test conditions should be able to reflect this. There are options that a test laboratory can consider when selecting challenge compoundsgases:

- a. If the intent of the test is to select an appropriate device for removal of a single chemical compoundecontaminant, the device is only required to be tested against that challenge compoundecontaminant.
- b. If the device is employed as part of a large HVAC system, the air is likely to contain a diverse mixture of compoundsecontaminants, typically ~~a large number of contaminants~~ at low concentrations. In this case it is more appropriate to test the device against several challenge compoundsecontaminants representing various common chemical groups to assess the combined performance. Two common groups of challenge ~~gases-compounds~~ are those with their sources primarily outdoors and those with primarily indoor sources. The outdoor air group can be used for testing devices to be employed in makeup (outside) air applications; the indoor group, for testing recirculated air applications; and both, for testing supply (mixed) air applications.

Outdoor air gaseous compoundsecontaminants are predominately two types: acidic and oxidizing. Acidic pollution is associated with burning coal, oxidizing with internal combustion engines. As cities have become more crowded with motor vehicles, these two types have merged. Now the three main pollutant gases found everywhere in the industrialized world are sulfur dioxide, nitrogen dioxide, and ozone. Others commonly found in outdoor air are hydrogen sulfide (sewer gas) and chlorine (cooling towers, road salt,

and wastewater treatment plants). See Tables B-1 and B-2 for other pollutants and their sources. Another useful group of compoundsecontaminants that should be considered are the gases listed in ASHRAE Standard 62.1.

As noted above, nitrogen dioxide is a significant outdoor pollutant. However, there are issues that make testing against it problematic for many of the air cleaners covered by this standard. This test method was designed assuming that the challenge compoundecontaminant and the effluent gases will be the same. However, because challenging an adsorbent (particularly carbon) with NO<sub>2</sub> may result in the production of NO, both of these gases must be monitored both upstream and downstream of air cleaners being tested with NO<sub>2</sub>.

Indoor gaseous compoundsecontaminants will vary greatly between buildings, depending on the indoor sources and the level of outdoor air infiltration. However, VOCs and aldehydes are common gaseous compoundsecontaminants and may be present from the use of personal care products or from furniture and carpet emissions, food and food preparation, and occupant activities. Thus, there are many compounds that are considered relevant for testing in both the VOC and aldehyde categories. Although Standard 145.2 requires a specific gas from each category, it is recommended that, if a building is known to have a specific gaseous compoundecontaminant of interest or a specific air cleaner will be used predominantly for a specific compound, testing should be performed for that gas in addition to the required compound.

A single temperature and RH is used in this standard test procedure to control the possible impact on the removal mechanisms of the device. If nonstandard testing at other temperatures and relative humidities would be useful, the following values are suggested:

- a. 43°C and 0°C (110°F and 32°F) at 50% rh
- b. 32°C (90°F) at 90% rh
- c. 27°C (80°F) at 65% rh



**TABLE B-1 Common Emissions of Natural and Industrial Sources**

Natural Sources	Emissions
Microbes	H <sub>2</sub> , NH <sub>3</sub> , NO <sub>x</sub> , H <sub>2</sub> S, CO, large variety of organics of many types
Sewage	NH <sub>3</sub> , aldehydes, many organics, H <sub>2</sub> S, mercaptans, H <sub>2</sub> , S, CO
Geothermal	H <sub>2</sub> , H <sub>2</sub> S, SO <sub>2</sub>
Marshy area	H <sub>2</sub> S, NH <sub>3</sub> , SO <sub>2</sub>
Animal matter	Many organics, mainly oxygenated
Forest fires	HCl, CO, CO <sub>2</sub>
Oceans	NaCl, chloride ions
Commercial Sources	Emissions
Automotive combustion	SO <sub>2</sub> , SO <sub>3</sub> , HCl, HBr, NO <sub>x</sub> , hydrocarbons, organics, CO
Diesel combustion	CO, NO <sub>x</sub> , many organics
Food processing	Aldehydes, H <sub>2</sub> S, mercaptans, hydrocarbons, many organics
Tobacco smoke	H <sub>2</sub> S, SO <sub>2</sub> , HCN, CO, tars and particulates
Animal research facilities	NH <sub>3</sub> , amines, large variety of organics of many types
Office buildings	HCHO,
Controlled atmosphere storage	C <sub>2</sub> H <sub>4</sub> , reactive sulfur species, many organics
Building exhaust	many organics
Industrial Sources	Emissions
Power generation	SO <sub>2</sub> , C, CO, NO <sub>x</sub> , hydrocarbons, organics
Automotive combustion	SO <sub>2</sub> , SO <sub>3</sub> , HCl, HBr, NO <sub>x</sub> , hydrocarbons, organics, CO
Diesel combustion	CO, NO <sub>x</sub> , many organics
Fossil fuel processing	H <sub>2</sub> S, S, SO <sub>2</sub> , NH <sub>3</sub> , hydrocarbons, other organics, mercaptans
Plastic manufacturing	All organics, aldehydes, alcohols, NH <sub>3</sub> , SO <sub>2</sub>
Cement plants	SO <sub>3</sub> , SO <sub>2</sub> , NO <sub>x</sub> , CO
Steel blast furnaces	H <sub>2</sub> S, SO <sub>2</sub> , CO, HF
Steel electric furnaces	H <sub>2</sub> S, SO <sub>2</sub> , C, CO
Coke plants	H <sub>2</sub> S, CO, HCN, carbon
Pulp manufacturing	Cl <sub>2</sub> , SO <sub>2</sub> , H <sub>2</sub> S, CO, wood fibers
Semiconductor manufacturing	AsH <sub>3</sub> , HF, HCl, NH <sub>3</sub> , SO <sub>2</sub> , NO <sub>x</sub> , CH <sub>3</sub> COOH, many organics
Chlorine plants	Cl <sub>2</sub> , chlorine compounds, NaCl
Fertilizer manufacturing	HF, NH <sub>3</sub> , CH <sub>4</sub> , gas, liquids, acids
Rubber manufacturing	H <sub>2</sub> S, S <sub>8</sub> , R-SH
Paint manufacturing	C, hydrocarbons, oxygenated hydrocarbons
Aluminum manufacturing	HF, SO <sub>2</sub> , C
Ore smelting	SO <sub>2</sub> , CO, H <sub>2</sub> S
Gasoline and fuel vapors	Hydrocarbons, oxygenated hydrocarbons
Battery manufacturing	SO <sub>2</sub> , acids

**TABLE B-2 Common Sources of Reactive Environmental Gaseous CompoundsContaminants**

Category	Constituent	Symbol	Common Sources
Gas	Hydrogen sulfide	H <sub>2</sub> S	Geothermal emissions, microbiological activities, fossil fuel processing, wood pulping, sewage treatment, combustion of fossil fuel, auto emissions, ore smelting, sulfuric acid manufacture
Gas	Sulfur dioxide	SO <sub>2</sub> , SO <sub>3</sub>	Combustion of fossil fuel, auto emissions, ore smelting, sulfuric acid manufacture, tobacco smoke
Gas	Mercaptans	S <sub>8</sub> , R-SH	Foundries, sulfur manufacture
Gas	Hydrogen fluoride	HF	Fertilizer manufacture, aluminum manufacture, ceramics manufacture, steel manufacture, electronic device manufacture, fossil fuel
Gas	Oxides of nitrogen	NO <sub>x</sub>	Automobile emissions, fossil fuel combustion, microbes, chemical industry
Gas	Active organic nitrogen	N <sub>2</sub>	Automobile emissions, animal waste, vegetable combustion, sewage, wood pulping

BSR/ASHRAE Addendum c to ANSI/ASHRAE Standard 145.2-2016, *Laboratory Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Air Cleaning Devices*  
 Second Public Review Draft

Gas	Ammonia	NH <sub>3</sub>	Microbes, sewage, fertilizer manufacture, geothermal steam, refrigeration equipment, cleaning products, reproduction (blueprint) machines
Solid	Carbon	C	Incomplete combustion (aerosol constituent), foundry
Gas	Carbon monoxide	CO	Combustion, automobile emissions, microbes, trees, wood pulping
Gas	Chlorine, Chlorine dioxide	Cl <sub>2</sub> , ClO <sub>2</sub>	Chlorine manufacture, aluminum manufacture, paper mills, refuse decomposition, cleaning products
Gas	Hydrogen chloride	HCl	Automobile emissions, combustion, oceanic processes, polymer combustion
Gas	Halogen acids	HBr, HI	Automotive emissions
Liquid	Chloride ions	Cl <sup>-</sup>	Aerosol content, oceanic processes, ore processing
Gas	Ozone	O <sub>3</sub>	Atmospheric photochemical processes mainly involving nitrogen oxides and oxygenated hydrocarbons, automotive emissions, electrostatic filters, air ionizers
Gas	Hydrocarbons	HC, THC	Automotive emissions, fossil fuel processing, tobacco smoke, water treatment, microbes. Many other sources, both natural and industrial, paper mills
Gas	Acetic acid	CH <sub>3</sub> COOH	Semiconductor manufacturing, wood and wood products, photo developing
Gas	Arsine	AsH <sub>3</sub>	Semiconductor manufacturing
Gas	Ethylene	C <sub>2</sub> H <sub>4</sub>	Fruit, vegetable, cut flower storage & transportation
Gas	Formaldehyde	HCHO	Wood products, floor & wall coverings, adhesives, sealants, photo developing, tobacco smoke

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## INFORMATIVE APPENDIX C GAS-PHASE AIR-CLEANER PERFORMANCE THEORY

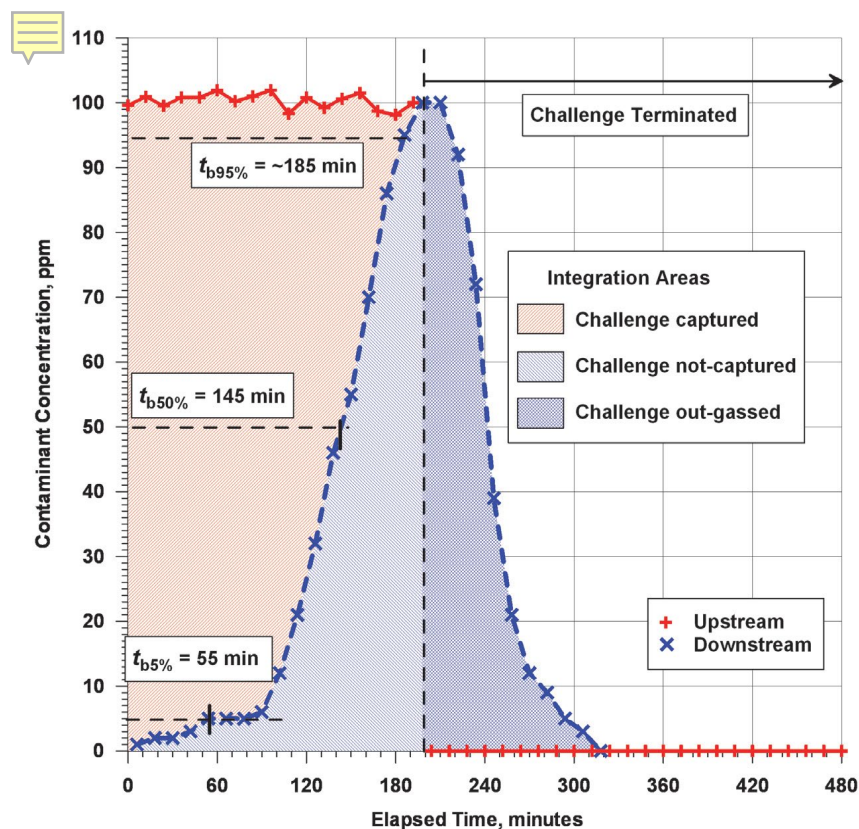
### C1. SORPTIVE AIR-CLEANER TEST OVERVIEW

The inlet and outlet concentration data from a gas-phase test may be plotted at the test conclusion to define the shape of the sorption curve to the point of breakthrough, and the desorption curve following cessation of the challenge concentration. Figure C-1 shows a gas-phase air cleaner (or a single medium) challenged with a physically adsorbing chemical at a concentration that has a relatively rapid breakthrough time. Apparent from the downstream trace at times less than ~100 minutes is a small bypass of challenge gas compound (<5%) due to either channeling through the device (media) or bypass around the device. The “challenge captured” concentration (by volume) is converted to mass and integrated and then adjusted for the mass of “challenge not captured” to determine capacity.

If, as shown in Figure C-1, downstream concentration measurements continue after the challenge generation is terminated, and clean, conditioned air is allowed to purge the air cleaner, then desorption may be measured. The cross-hatched area under the “challenge outgassed” portion of the outlet concentration curve is integrated to determine the mass of challenge desorbed. Deducting the mass desorbed into clean air from the challenge captured defines the air-cleaner retentivity. When the capacity and retentivity are identical, it follows that no challenge mass has been lost during desorption.

Breakthrough curves for other media/chemical combinations or air-cleaner configurations may be very different. Air cleaners with long breakthrough times, usually those with deep beds, may show little or no measurable outlet concentration during the standard test challenge times required under this method. Chemisorbed challenges may exhibit only minor ~~off-gassing~~ (desorption). However, desorbed challenge gas compound may still be out-gassed during clean-air purging, even with no breakthrough during the active challenge period. In contrast, an energetic air-cleaning device, such as a photocatalytic oxidation (PCO) air cleaner, would be expected to have a different performance characteristic. A single-pass efficiency of only 10% might be obtained (e.g., a downstream concentration of 90 ppm for a 100 ppm upstream challenge). However, very little deterioration in performance would be expected over the standard test period.

The time required for the challenge gas compound to penetrate to specific levels provides important information on both the degree of removal upon breakthrough, and on the rapidity with which the capacity is subsequently exhausted beyond this point. If the challenge concentration is 100 ppm, the times to reach 5 ppm and 5% (for example) are identical. For other challenge concentrations, the penetration must be calculated to determine the 5% breakthrough time, denoted as  $t_{b5}$ . A 5% breakthrough is nominally defined here as the time required for the first measurable indication of breakthrough within the experimental error of the method. This considers that the sensitivity of typical analytical measurements for the challenges defined here usually do not permit a more definitive indication of initial breakthrough. The example in Figure C-1 shows a  $t_{b5}$  of 55 minutes, while the time to 50% breakthrough,  $t_{b50}$  in the example, was 145 min.



**FIGURE C-1 Example of temporal inlet challenge and outlet concentration trends, illustrating the challenge and outgassing desorption periods. The regions integrated to compute media capacity and retentivity are shown, along with the breakthrough times.**

Nelson and Correia (1976) developed the following equation to calculate the same percentage ( $X\%$ ) breakthrough time at lower ( $c_{low}$ ) or higher ( $c_{high}$ ) challenge concentrations, based on empirical volatile organic compound data:

$$t_{bX_{High}} = t_{bX_{Low}} \left( \frac{c_{Low}}{c_{High}} \right)^{2/3} \quad (C-1)$$

This equation was developed for physically adsorbed hydrocarbons on activated carbon and may be cautiously used for test planning. It will have significant error for some compound contaminants on some filters/air cleaners.

The 50% ( $t_{b50}$ ) time has been reported in the literature (VanOsdell et al. 1996) as a useful and relatively easily reproduced midlevel indicator of air-cleaner performance. In many applications, disposable gas-phase filters might be slated for replacement at removal efficiencies of 40% to 60% because the gaseous compound contaminants (odors) of concern may have returned to unacceptable levels.

The time to 95% breakthrough ( $t_{b95}$ ) (in the example of Figure C-1 it is approximately 185 minutes) are less commonly reported because of the experimental time required to make the determination. Note that although a near 100% breakthrough time allows the determination of the total capacity, the value of this

information may be marginal, given the relatively high level of downstream concentrations allowed at the longer breakthrough times. Because some media may have exceptionally long periods to transition from 95% to 100%, a nominal 95% breakthrough time ( $t_{b95}$ ) is sometimes reported.

Other useful values may be calculated from the data. Penetration, removal efficiency, and capacity for removal calculations are shown in Section 10. Figure C-2 shows an example (lower plot) of plotting the penetration and efficiency versus elapsed challenge time (beyond the conditioning period). Note that efficiency during clean-air purge ~~outgassing~~ desorption (after 100% breakthrough is reached) is assumed to be 100%.

Another commonly calculated value is the calculation of retentivity ( $R_c$ ) (mass). Because Standard 145.2 does not require 100% breakthrough, this calculation is not required for this method. The following equations and discussion are provided to improve understanding of the use of the data.

Retentivity represents the amount of the challenge ~~gas-compound~~ capacity that is retained by the air-cleaner media during the ~~off-gassing~~ desorption portion of the test when the air cleaner is purged with conditioned, clean air only (no challenge). The retentivity is then computed by Equation C-2 using the outlet concentration. This is done by adjusting the challenge capacity to 50% breakthrough ( $C_{R50}$ ) by the capacity (weight) lost during ~~off-gassing~~ desorption with a clean-air challenge.

$$R_{C_{50}} = C_{R_{50}} - Q \sum_{n=1}^N \frac{(C_i - C_{o_i})(MW)(28.317)(t)}{(10)^6(24.414)} g \quad (C-2)$$

where

- $N$  = the total number of time increments to  $TD$ , the total desorption time, min
- $T$  = length of interval, min
- $C_i$  = inlet challenge ~~gas-compound~~ concentration (in ppm) for the interval
- $C_o$  = outlet (media downstream) ~~gas-challenge compound~~ concentration (in ppm) at time  $t$
- $MW$  = molecular weight of challenge ~~compound~~gas
- $Q$  = airflow rate for the test, cfm

Using Equation C-2, other retentivity values, such as  $R_{4h}$ , may be computed. Using the values obtained for the 4-hour capacity in Section 10, the corresponding retentivity may be calculated.

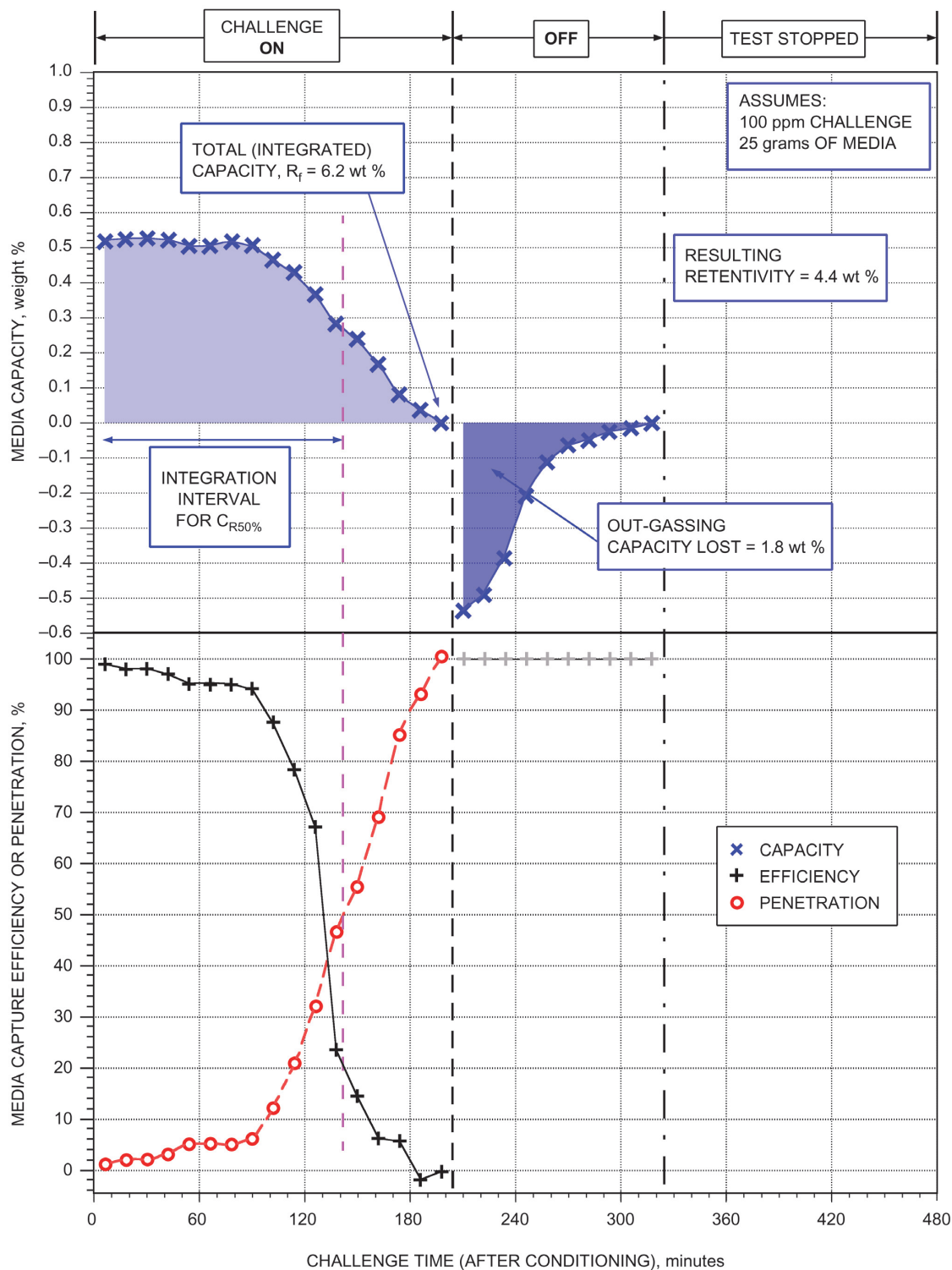


FIGURE C-2 Examples of media efficiency and capacity versus challenge time (a logarithmic time scale is optional).

**(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)**

## **INFORMATIVE APPENDIX D HOW TO READ A TEST REPORT**

### **D1. BACKGROUND**

This appendix provides background information about the test report and explains the standard's test method in layman's terms for nonexpert users (building owners, installers, and design engineers).

**D1.1** ASHRAE does not actually test air-cleaning devices or determine their performance but only specifies the test procedure to be used by manufacturers and test laboratories.

**D1.2** Air-cleaner testing in a laboratory is intended to help the user compare the performance of different types of air cleaners. Standard 145.2 testing attempts to simulate the performance of air-cleaning devices in real-life operation but cannot duplicate field conditions because conditions vary from location to location. The reporting values obtained in accordance with this standard cannot be used by themselves to predict the air cleanliness of a specific ventilated space or the service life of installed air-cleaning devices.

**D1.3** The Standard 145.2 test involves concentrations and compositions that are almost certain to be different from those the air-cleaning device will encounter when installed in a system. Also, the airflow rate, final resistance to airflow, and temperature and humidity level of the air may be different in the testing laboratory from those on the job.

**D1.4** This version of Standard 145.2 includes many changes from 145.2-2016 related to the inclusion of additional types of air cleaners and awareness that some air cleaners add chemicals to the air either intentionally to clean the air or due to reactions intended to remove the target compound~~contaminant~~. To address this, commonly produced by-product species are now measured. ~~The~~ However, removal efficiency of the device is now calculated both based only on the challenge compound~~contaminants and on the contaminant and the by-products.~~

**D1.5** After a relatively low concentration 1-hour test, Standard 145.2 allows a choice of continuing the low concentration test to show stability in operation (intended especially for devices that do not capture gaseous compound~~contaminants~~ and lose efficiency over life) or a high concentration test intended to determine a capture capacity and to show possible changes in removal efficiency with loading. Full test reports should include data for one of the two options.

### **D2. READING A TEST REPORT**

**D2.1** ~~The summary section of a~~ A sample performance report for a fictional gas-phase air-cleaning device is shown in Figures D-1 through D-5. A description of each section of the report and important components within each section are provided below. The numbers inside the parentheses in Figures D-1 through D-5 correspond to the notes below.

- a. **The Test Method.** The test method should be the latest edition of ASHRAE Standard 145.2 to ensure the testing laboratory is following the most up-to-date procedures.
- b. **Laboratory Data.** This section provides information about the test laboratory and its testing equipment.
- c. **Sampling Techniques, Analyzer Details, and Pull Sample Analytical Methods.** Sampling Techniques provide information on the number of rig sampling ports and whether a manifold has been used to transport sampled air from the duct to analyzers and pull sample pumps. Analyzer Details lists the direct-reading instruments used to measure gaseous compound~~contaminants~~, along with the model, analytical technique involved, and the lower detection limit for each. Pull Sample Analytical Methods list the methods used to quantify gaseous compound~~contaminants~~ collected by pull samples, along with the analytical technique involved, and lower detection limit for each.
- D. **Device Manufacturer's Data.** This section is helpful for tracing information about the tested device, including the manufacturer and model. The information is obtained from brochures or websites and constitutes the manufacturer's claims.
- e. **Catalog Rating.** If the manufacturer's catalog data are available and included in the test report, it will help the user compare published data to actual performance.
- f. **Device Description.** The testing laboratory uses this section to provide information on the tested device. This information includes a physical description and the type of air cleaning technologies used in the device.
- g. **Specified Test Conditions.** The test requester specifies the test conditions. The first item to check is which version of the test was run, the extended steady-state efficiency or the Capacity test. All tests include the same Initial efficiency test which is followed by one of these choices. Other test conditions may represent the in-use air velocity and the expected challenge gas compound to the air cleaner or a set of conditions desired to compare air-cleaning devices. The test air velocity, and hence the airflow rate, generally depends on the device size (height, width, and depth), the air cleaner face area, and air cleaner construction. The challenge gas compound is usually selected from Table 6-1, "Standard Test Challenge Gases/Compounds." Also included are the pre-conditioning time used and the upstream and downstream T and RH that verify completion of pre-conditioning.
- h. **Initial and Final Resistance to Airflow.** The initial resistance to airflow is the resistance to airflow across the device after the equilibration time period during the initial efficiency test at the specified test flow rate. The final pressure drop is the resistance to airflow of the device at the end of the capacity test at the specified test flow rate. Resistance to airflow information at various airflows is in tabulated form. Resistance to airflow is synonymous with initial pressure drop and is the resistance to airflow in the air cleaner at the test airflow rate. This value is important for designing HVAC systems to use a specific air-cleaning device and for determining if the device is acceptable for an existing system.
- i. **Test Conditions.** The testing laboratory uses this section to provide information on the achieved test conditions. These should be similar or equal to the specified test conditions.
- j. **Initial Removal Efficiency Test Results.** The removal efficiency reported from the initial removal efficiency test (low concentration) is the average removal efficiency over the 1-hour initial removal efficiency test period. The penetration is the average penetration over this test period. The reported upstream concentration is the average of the measured values during this test period. Tabulated data and respective plots are on the following pages. The initial removal efficiency is the result of this specific test and, as such, the data do not necessarily reflect actual field performance but allow comparison of air cleaners. Also included are the concentrations found for major by-products; and the by-product production percentage (BPP); ~~and the average corrected removal efficiency and penetration calculated using the BPP.~~ The presence of both challenge gas compound and by-products downstream of the air cleaner means that the ~~corrected~~ effective penetration is larger than the value determined using only the challenge gas compound concentrations. Correspondingly, the ~~corrected~~ effective



removal efficiency is smaller than the value determined using only the challenge ~~gas~~-compound concentrations.

- k. **Extended Steady-State Removal Efficiency Test Results.** This test shows whether a device maintains its removal efficiency and by-products levels, so the data shown includes concentrations and calculated removal efficiencies.
- l. **Removal Capacity Test Results.** The removal capacity results are related to the removal capacity test (high concentration). The report documents removal capacities at the start of the test and at test end. The reported average upstream concentration is the average of the measured values during this test period. Tabulated data and respective plots are provided on the following pages. The report includes the desorption time, but the amount of desorption found is shown only in the plots and the tabulated data.

ASHRAE Std 145.2-2024 <sup>(a)</sup> Gas-Phase Air Cleaner Performance Report (This report applies only to the device tested.)			
<b>Laboratory Data<sup>(b)</sup></b>			
Report Number	<i>T06062022</i>	Date	<i>6/6/2022</i>
Test Laboratory	<i>Test LAB</i>	Supervisor	<i>Smith</i>
		Operator	<i>Jones</i>
Sampling Techniques <sup>1</sup>	<i>Gas samples obtained through single port with stainless steel transport to manifold where individual samples are obtained</i>		
<b>Analyzer Details<sup>1</sup></b>			
<u>Compound</u> <u>Contaminant</u>	Model	Technique	Detection Limit
<i>Ozone</i>	<i>BestO<sub>3</sub></i>	<i>thermoluminescence</i>	<i>3 ppb</i>
<i>Particles</i>	<i>Counts</i>	<i>optical</i>	<i>1 part/cc</i>
<b>Pull Sample / Analytical Methods<sup>1</sup></b>			
<u>Compounds</u> <u>Contaminants</u>	Method	Technique	Detection Limit
<i>VOCs, all</i>	<i>EPA TO-1</i>	<i>GC-MS</i>	
<i>Aldehydes, all</i>	<i>EPA TO-5</i>	<i>HPLC</i>	
<b>Device Manufacturer's Data<sup>(d)</sup></b>			
Manufacturer	<i>Air Filter Maker</i>	Test Requested by	<i>Air Filter Maker</i>
Product Name	<i>Carbon Blend</i>	Sample Obtained from	<i>Open market</i>
Product Model	<i>Clean Air 6</i>	Serial Number	<i>XYZ123</i>
Catalog Rating <sup>1</sup>	<i>Not rated</i>	Rated Airflow	<i>2000 cfm</i>
Initial resistance to airflow	<i>0.3 in H<sub>2</sub>O</i>	Rated Face Velocity	<i>500 cfm</i>
Final resistance to airflow	<i>1.0 in H<sub>2</sub>O</i>	Residence Time	<i>0.12 s</i>
<b>Device Description<sup>(f)</sup></b>			
Nominal Dimensions	<i>24x24x12 in</i>	Physical Description	<i>Impregnated media pleats with ionizer after</i>
Technologies	<i>Carbon filter and ionizer</i>	Other	<i>Media appears brown</i>
<b>Test Conditions<sup>(g)</sup></b>			
Test Type (Extended steady-state efficiency or Capacity): <i>Extended steady-state efficiency</i>			
Challenge Compound/Gas/Conc.	<i>Toluene / 400 ppb</i>	Airflow	<i>2000 cfm</i>
Temperature	<i>75.2 F</i>	Face Velocity	<i>500 fpm</i>
RH	<i>49.8 %</i>	Final Resistance to Airflow	<i>0.32 in. H<sub>2</sub>O</i>
Preconditioning Time	<i>15 min</i>	Preconditioning T/RH (final)	<i>US=76.1 F, 50.1% DS=76.2 F, 50.0%</i>
Remarks			
<b>Resistance to Airflow Test<sup>(h)</sup></b>			
Airflow (cfm)	Resistance to Airflow (in. w.g.)	Airflow (cfm)	Resistance to Airflow (in. w.g.)
<i>1000</i>	<i>0.15</i>	<i>2500</i>	<i>0.37</i>

1500	0.21	3000	0.46
2000	0.29		

**FIGURE D-1 Example Standard 145.2 report (superscript numbers in parentheses refer to explanations of terms located at the beginning of Section D2).**

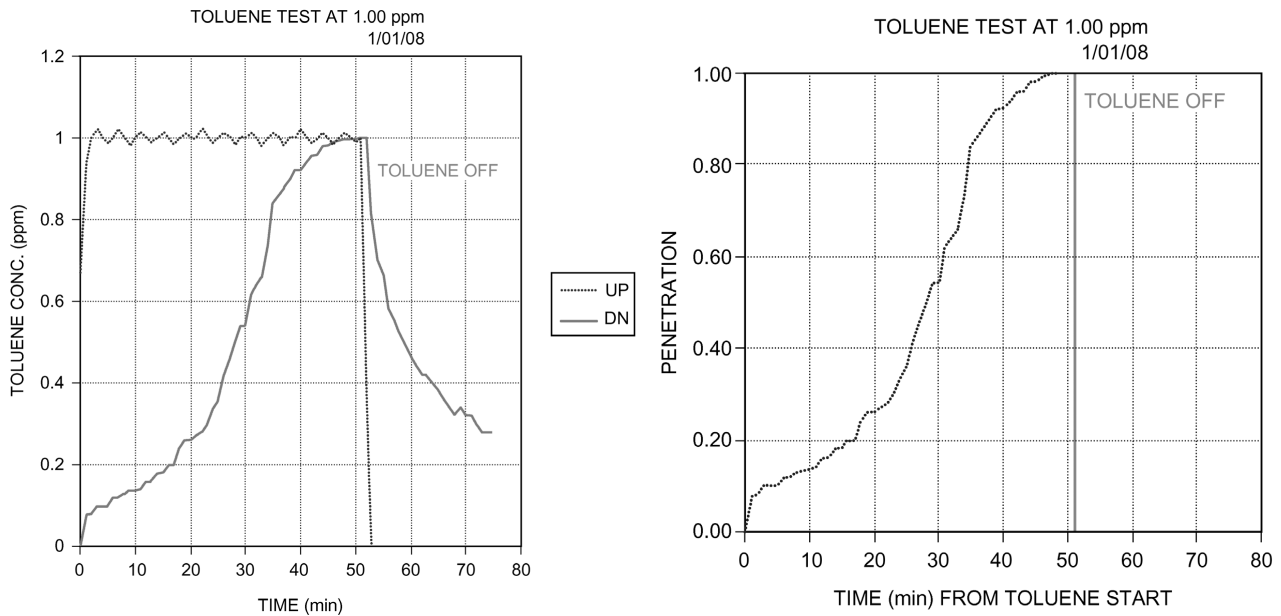
ASHRAE Std 145.2-20224 <sup>(a)</sup> Gas-Phase Air Cleaner Performance Report (This report applies only to the device tested.)			
<b>Initial Removal Efficiency Test Results<sup>(j)</sup></b>			
Challenge Compound <sup>(i)</sup>	<i>Toluene</i>	By-product(s) Conc., Individual and Total	
Upstream Conc. <sup>(i)</sup>	<i>402 ppb</i>	Chemical	Concentration ( <del>ppb</del> <sup>μg/m<sup>3</sup></sup> )
<u>Resistance to Airflow Pressure drop</u> <sup>(i)</sup>	<i>0.29 in. w.g.</i>	<i>Ozone</i>	<i>0</i>
		<i>Formaldehyde</i>	<i>20</i>
Average Removal Efficiency (%)	<i>75%</i>	<i>acetaldehyde</i>	<i>4</i>
Average Penetration	<i>0.25</i>	total	<i>24</i>
Challenge Gas-Compound Correlation	<i>1.00</i>	<u>BPP (%)</u>	<u><i>6</i></u>
Average Corrected Removal Efficiency (%)	<del><i>69%</i></del>	<u>BPP (%)</u>	<i>6</i>
Average Corrected Penetration	<del><i>0.31</i></del>		
<b>Extended Steady State Test Results<sup>(k)</sup></b>			
Time (hr)	<u>Corrected Removal Efficiency (%)</u>		
<i>1</i>	<i>NA</i>		
<i>2</i>	<i>NA</i>		
<i>3</i>	<i>NA</i>		
<i>4</i>	<i>NA</i>		
Removal Efficiency Stability Statement, if earned			
<b>Removal Capacity Test Results<sup>(l)</sup></b>			
Upstream Conc	<i>50 ppm</i>	Total Challenge Time	<i>240 min</i>
Final <u>Resistance to Airflow Pressure Drop</u> <sup>(h)</sup>	<i>0.31 in. w.g.</i>	<u>Removal Capacity at 95% Breakthrough</u>	<i>25 g</i>
<u>Removal Efficiency Time to 5% Breakthrough, t<sub>b5</sub></u>	<i>69% at 5 min</i>	<u>Removal Capacity at 4 Hours</u>	<i>N/A</i>
<u>Removal Efficiency Time to 50% Breakthrough, t<sub>b50</sub></u>	<i>67% at 240 min</i>		
<u>Removal Efficiency Time to 95% Breakthrough, t<sub>b95</sub></u>	<i>90 min</i>		
<u>Removal Efficiency Time to 100% Breakthrough, t<sub>b100</sub></u>	<i>N/A</i>		






**FIGURE D-4 Example Standard 145.2 report page 4 (superscript numbers in parentheses refer to explanations of terms located at the beginning of Section D2).**

ASHRAE Std 145.2-2024 Gas-Phase Air Cleaner Performance Report (This report applies only to the device tested.)
<b>Capacity Test Graphs</b>



**FIGURE D-5 Example Standard 145.2 report page 5 (superscript numbers in parentheses refer to explanations of terms located at the beginning of Section D2).**

**(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)**

## **INFORMATIVE APPENDIX E APPLICATION GUIDELINES**

### **E1. SELECTION OF CHALLENGE COMPOUND~~TEST CONTAMINANT CHEMICALS~~**

The most useful data are obtained when the test challenge compound~~contaminant~~ is as close as possible in chemical properties and concentration to that of the challenge expected in the desired use. Ideally, the air cleaner should be tested with the expected challenge compound~~contaminant~~.

These ideal circumstances are seldom possible. For some applications, the challenge chemical is known but the concentration is not constant. In others, the challenge could be determined through extensive testing, but resources are not adequate to the task. In many cases, the challenge is not constant in either its composition or its concentration.

Section 6 of this standard presents challenge contaminant compound and concentration recommendations that are representative of those one might encounter in common applications and that will adequately challenge the air-cleaning device to determine its effectiveness under the conditions specified. Other challenge gaseous compounds may also be chosen and used with the methodology of this test. *ASHRAE Handbook—Fundamentals*, Chapter 11, “Air Contaminants,” discusses the current state of knowledge with regard to outdoor and indoor air gaseous compound~~contaminants~~ and their concentrations (ASHRAE 2009).

Adsorption, both physical and chemical, is a complex phenomenon with many influential variables, including the adsorption medium, the nature of the gaseous compound~~contaminants~~ in the airstream, the RH, and the temperature. Important factors for an individual medium include the types and amounts of media in the air-cleaning device. The number, type, and concentrations of gaseous compound~~contaminants~~ influence the level of adsorption. The RH effects will vary over the range of humidities because the moisture can collect in the medium pores at high humidities, thus reducing the available surface area for physical adsorption. The level where this becomes important may vary by medium and by gaseous compound~~contaminant~~.

A full discussion of these phenomena is beyond the scope of this test method. It is highly recommended that anyone attempting to extrapolate from the test data review the literature, including, but not limited to, the references included in the Appendix F of this document.

The following sections present possible methods for extrapolating the data generated using this test method. Previous studies have shown deviations from experimental results from 50% to order of magnitude ranges. However, they may be acceptable for use in a comparison of potential air-cleaning devices being considered for a specific application.

### **E2. EXTRAPOLATION OF CHEMICAL PERFORMANCE DATA FOR SORPTIVE DEVICES TO ANOTHER CONCENTRATION**

The following discussion describes the use of extrapolation based on media bed depth. For a full-scale air-cleaning device, the depth for this type of extrapolation is the depth of the media. Thus a 12 in. (300 mm) deep air cleaner may need to be considered a 1 in. (25 mm) deep bed if that is the depth the media would have within a larger housing.

When a challenge compound is fed at constant concentration and constant gas flow rate to an adsorber with a sufficient bed depth,  $L$ , the gas stream concentration varies with time and bed depth, as shown in Figure E-1A. When bed loading begins, the challenge compound concentration decreases logarithmically with bed depth, deeper into the bed, the slope of the concentration-versus-bed depth curve flattens at a very low value. At later times, the entrance portion of the adsorber bed becomes loaded with challenge compound, so challenge compound concentrations in the gas stream are higher at each bed depth.

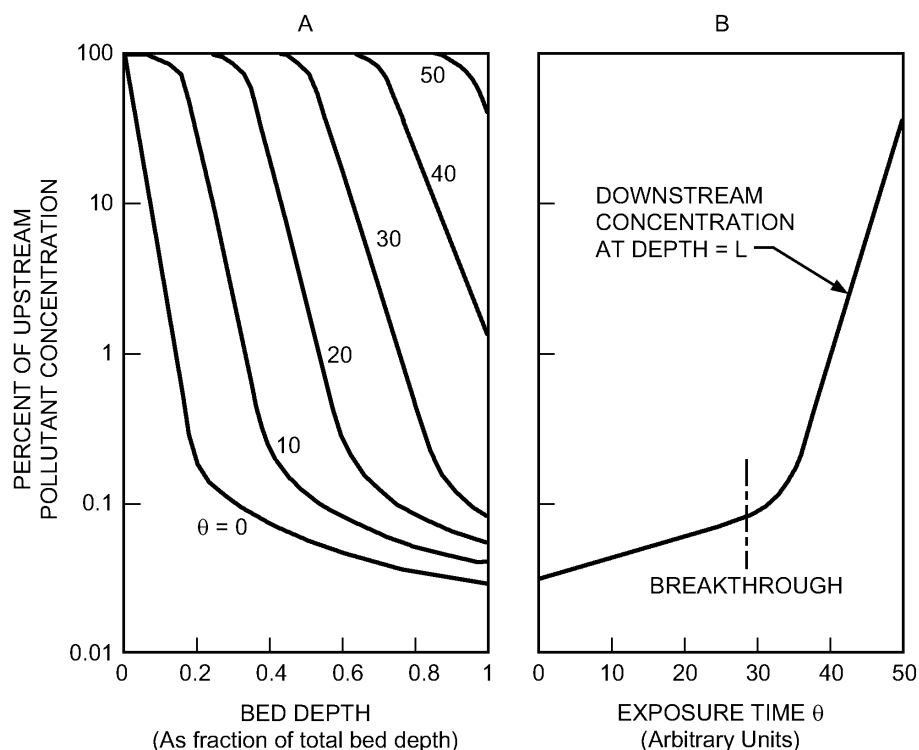
For the same constant challenge compound feed, the pattern of outlet concentration versus time for an adsorber of bed depth ( $L$ ) is shown in Figure E-1B. Usually the outlet concentration is very low until a point at which the concentration rises rapidly until the outlet concentration is the same as the inlet. This penetration is called breakthrough, because it tends to occur suddenly. Not all adsorber/compound combinations show as sharp a breakthrough as Figure E-1B might indicate.

Multiple challenge compounds produce more complicated penetration patterns than shown in Figure E-1B. While individually each compound might behave as shown in Figure E-1, each would have its own time scale. The better adsorbing compounds will be captured in the inlet portion of the bed, and the poorer adsorbing deeper. As the challenge continues, the better adsorbing compound will progressively displace the other until finally the displaced component can leave the adsorber bed at a higher concentration than it entered. On carbon, water constitutes a special case of competitive adsorption. Carbon does not adsorb water well, but water vapor is present in concentrations far (orders of magnitude) above the challenge compound concentrations. It therefore competes for sites with an effect that varies as a function of RH.

Yoon and Nelson (1988) and Underhill et al. (1988) discuss the effect of RH on physical adsorption. Essentially, water vapor acts as a second challenge compound, altering the adsorption parameters by reducing the amount of the first challenge compound that can be held by the adsorber and shortening the breakthrough times. The specific effects of humidity are different for different chemicals, depending on their chemical properties, such as boiling points, polarity, and solubility in water. For simple VOCs adsorbed on carbon, the effect of relative humidity is reported to be modest up to about 50% rh, but greater at higher relative humidities.

**E2.1 Physical Adsorption Performance.** In spite of the complexity of physical adsorption, comparatively simple expressions have been developed to describe the behavior of adsorbers. Expressions fitting available test data over a wide range of operating conditions for many pollutants are given in articles by Nelson and Correia (1976) and by Yoon and Nelson (1984a, 1984b, 1988).





**FIGURE E-1** Dependence of gaseous compound contaminant concentration on bed depth and exposure time.

The expressions apply to the case of constant flow and constant pollutant challenge inlet concentration. Nelson and Correia developed a semiempirical expression for an average organic compound:

$$\theta_{10} = K_{a1} C^{-0.67} \quad (\text{E-1})$$

where

$\theta_{10}$  = breakthrough time for an outlet concentration equal to 10% of inlet concentration  $K_{a1}$  = constant for a given adsorber/pollutant challenge combination, factors within this constant include adsorption media mass per unit airflow and pollutant molecular mass and boiling point

$C$  = inlet pollutant challenge concentration, ppmv

The concentration exponent ( $-0.67$ ) in Equation E-1 is the average value for several organic chemicals on the same carbon. The measured values ranged from  $-0.395$  to  $-0.937$ , and the standard deviation of the mean ( $-0.67$ ) was  $0.17$ . Use of Equation E-1 for extended extrapolations for an arbitrary compound is therefore problematic. Additional information and supporting data can be found in Nelson and Correia (1976).

Yoon and Nelson's articles present a more rigorous expression, giving the breakthrough time ( $\theta_b$ ) at any desired outlet/inlet concentration ratio:

$$\theta_b = \theta_{50} + K_{a2} \ln[C_b / (C - C_b)] \quad (\text{E-2}) \text{ where}$$

$\theta_{50}$  = breakthrough time for an outlet concentration equal to 50% of inlet concentration

$C_b$  = outlet (breakthrough) concentration, ppmv

$K_{a2}$  = constant determined experimentally for the adsorber/~~pollutant~~challenge combination by tests run at two inlet concentrations

Most studies, including those above, were run at concentrations of interest for short-term exposures ( $\leq 1000$  ppm), which may be misleading for the low-~~contaminant~~ concentrations encountered in HVAC applications. Low-concentration studies are reported by VanOsdell et al. (1996), VanOsdell and Sparks (1995), Miller and Reist (1977), Ostojic (1985), Nelson and Correia (1976), Stampfer (1982), and Jonas and Rehrmann (1972). All show that breakthrough time depends on inlet concentration. Yoon and Nelson (1984a) showed the equivalence between their expressions and those of Wheeler and Robell(1969) and Mecklenberg (1925) for low bed loadings.

These theories, assisted by the Dubinin-Raduskevich isotherm theory (Dubinin 1975), relate dynamic adsorption to isotherm data obtained under static equilibrium conditions. (An isotherm is a plot of equilibrium vapor mass adsorption as a function of vapor pressure.) Isotherms are, however, normally plotted over the complete pressure range from 0 to 101.325 kPa (0 to 1 atm). The range of interest for indoor pollutants (including chemical spills) is from about 0.0001 to 1000 Pa ( $10^{-9}$  to  $10^{-2}$  atm, or 1 ppb to 10,000 ppm), which is barely visible on such plots. The behavior at very low pressures cannot be reliably extrapolated from higher pressures.

VanOsdell and Sparks (1995) present data for toluene in which measured 10% breakthrough times for toluene on activated carbon are compared over approximately three decades of concentration down to about 0.4 ppm. Equation E-1 appears to hold over that range, except that the exponent is 0.78 rather than 0.67. Applying the method described by Jonas and Rehrman (1972), VanOsdell et al. (1996) computed low concentration (1 ppm and below) breakthrough times for several chemicals from handbook chemical parameters and measured carbon data obtained for a single compound, toluene. Comparison of the estimated and measured breakthrough times showed fair agreement (~50% for the similar compounds hexane and decane) and larger errors for the less similar methyl ethyl ketone and dichloroethane.

Yoon and Nelson (1988) and Underhill et al. (1988) discuss the effect of RH on physical adsorption. In essence, water vapor acts as a second pollutant, altering the adsorption parameters by reducing the amount of the first pollutant that can be held by the adsorber and shortening the breakthrough times. The simultaneous adsorption of several ~~pollutants~~compounds shortens breakthrough times in similar fashion. Jonas et al. (1983) calculate mixture breakthrough times at low bed loadings by determining the volumes of the individual components that the adsorber will hold separately, then summing the actual partial volumes (based on the partial pressures of each) to obtain an effective volume held for the mixture.

Several sources list maximum possible retentivity (mass of adsorbate held per mass of adsorbent) for various ~~pollutants~~compounds on typical activated charcoals. These values were normally obtained by tests with concentrations on the order of 1000 ppm and therefore grossly overestimate the amount of ~~pollutants~~compounds trapped at low indoor concentrations. Calculations based on such loadings should be viewed skeptically in determining the economic advantages of using adsorbers versus using increased ventilation rates. The maximum breakthrough time for an adsorber, assuming no concentration effect on removal efficiency (100% collection of ~~pollutant~~compounds), is

$$\theta_{max} = 1000 f_a W_a / Q_a C \quad (E-3)$$

where

$\theta_{max}$  = maximum breakthrough time, s

$W_a$  = mass of adsorbent in adsorber, g

$f_a$  = ratio of maximum pollutant compound mass adsorbed to adsorber mass, g/g

$Q_a$  = flow through the adsorber, m<sup>3</sup>/s

$C$  = inlet pollutant challenge concentration, mg/m<sup>3</sup>

ASTM *Standard D 3686* (ASTM 2008) lists maximum adsorptivities for about 130 vapors in high-quality activated carbons. In the standard, the column headed “Recommended Maximum Tube Loading, mg” represents the maximum percentage retentivity for the listed pollutants at *TWA8* levels. The percentage retentivities in ASTM D 3686 should be corrected to *TWA8* levels by the following equation, derived from Equation E-1 using the average exponent:

$$R_{TWA8} = R_{1000}(TWA8/1000)^{0.33} \quad (\text{E-4})$$

where

$R_{TWA8}$  = percent retentivity at *TWA8* pollutant challenge concentration in ppm

$R_{1000}$  = percent retentivity at pollutant challenge concentration of 1000 ppmv (test level used in ASTM D3686)

### **E3. EXTRAPOLATION OF PERFORMANCE DATA FOR ONE CHEMICAL TO A DIFFERENT CHEMICAL**

The most important step in extrapolating the data from one chemical to another is to choose data from a similar compound. In general, for compounds that physisorb, compounds that have a lower boiling point or molecular weight will break through more quickly.

### **E4. CHEMICAL ADSORPTION**

The three physical adsorption steps also apply to chemisorption. However, the third step in chemisorption is different from physical adsorption, for surface binding in chemisorption is by chemical reaction with electron exchange between the targetecontaminant molecule and the chemisorber. This action differs in the following ways from physical adsorption:

- Chemisorption is highly usually specific; only certain ~~contaminant~~ compounds will react with a particular chemisorbent.
- Chemisorption generally improves as temperature increases (reaction rate increases); physical adsorption improves as temperature decreases (vapor pressure drops).
- Chemisorption ~~does may~~ not generate heat but instead may require heat input.
- Chemisorption is not generally reversible. Once the adsorbed compoundecontaminant has reacted, it is not desorbed. However, one or more reaction products, different from the original compoundecontaminant, may be formed in the process, and these reaction products may enter the air as a new compoundecontaminant.
- Water vapor often helps chemisorption, or is necessary for it, while it usually hinders physical adsorption.
- Chemisorption by itself is a monomolecular layer phenomenon; the pore-filling effect that takes place in physical adsorption does not occur, except where adsorbed water condensed in the pores forms a reactive liquid.

Most chemisorptive media are formed by coating or impregnating a highly porous, nonreactive substrate (e.g., activated alumina, zeolite, or carbon) with a chemical reactant. The reactant will eventually become

exhausted, but the substrate may have physical adsorption ability that remains active when chemisorption ceases.

**E4.1 Chemisorption Performance.** Although the overall pattern of the concentration/time/bed depth relations in chemisorption is the same as described for physical adsorption, and the same equations apply, the rate constant  $K$  in Equations E-1 and E-2 depends on the kinetics of the chemical reaction between the pollutant compound and the chemisorber. Test data on individual chemisorber/pollutant compound combinations under operating conditions provide the only way to determine chemisorber performance in typical applications. However, the upper limit of capacity for a chemisorber/pollutant compound combination may be determined if both the chemical reaction at the surface and the amount of reactant available are known. A chemical reaction cannot involve more than stoichiometric amounts of the reactants unless catalytic effects are present.

Equation E-3 may be used for chemisorbers, with the following substitutions:

$W_a$  = mass of chemisorber reactant available for reaction, g

$f_a$  = number of grams of pollutant compound that combines stoichiometrically with each gram of reactant

~~Solid chemisorbers may be porous, chemically homogeneous materials, but this is usually wasteful and ineffective because only the exposed (generally small) surface reacts with the pollutant. For this reason, most chemisorptive media are formed from a highly porous support (e.g., activated alumina or activated carbon) coated or impregnated with a chemical reactant. The mass  $W_a$  is the mass of the reactant, not of the entire support. The support may have physical adsorption ability that comes into play when chemisorptive action ceases.~~

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## **INFORMATIVE APPENDIX F**

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### **INFORMATIVE APPENDIX G**

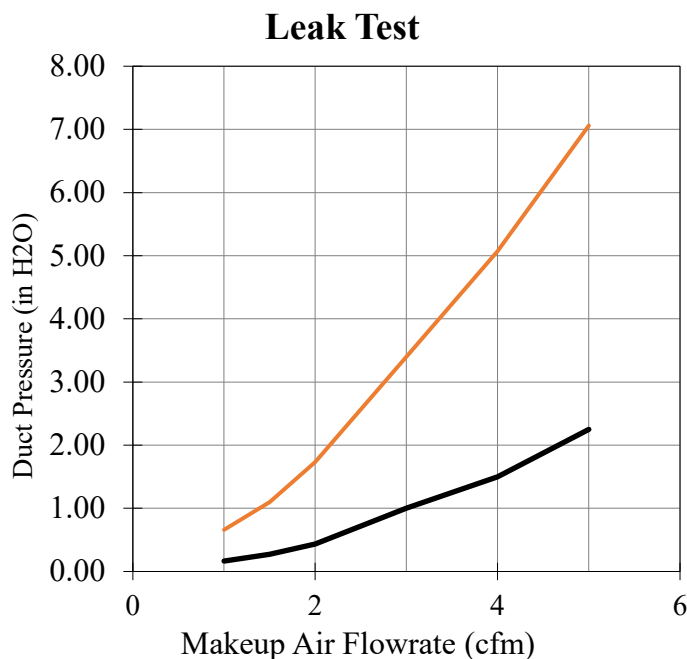
#### **TEST SECTION LEAKAGE TEST EXAMPLE (for Section 5.2)**

This example is based on a 6-point pressure vs makeup air flowrate data set where one set was taken, then a leak was found. The 6-point curve was repeated after the leaks were sealed.

#### **Leak Test Example**

<b><u>Makeup Air Flowrate</u></b>	<b><u>Duct Pressure</u></b>	<b><u>Duct Pressure after Sealing Leaks</u></b>
<b><u>(cfm)</u></b>	<b><u>(in. H2O)</u></b>	<b><u>(in. H2O)</u></b>
<u>1</u>	<u>0.17</u>	<u>0.66</u>
<u>1.5</u>	<u>0.28</u>	<u>1.10</u>
<u>2</u>	<u>0.43</u>	<u>1.73</u>
<u>3</u>	<u>1.00</u>	<u>3.40</u>
<u>4</u>	<u>1.50</u>	<u>5.07</u>
<u>5</u>	<u>2.25</u>	<u>7.06</u>

This is the graph (not required, but useful) resulting from this data set.



To show compliance with this data, the test lab uses the airflow vs pressure in the rig data taken in Section 5.2. The table below shows how this can be done.

<u>Airflow in Empty Rig</u>	<u>Duct Pressure</u>	<u>Add 1 in.</u>	<u>Allowed Leakage (1%)</u>	<u>Makeup Air from graph</u>	<u>≤1%</u>
<u>(cfm)</u>	<u>(in. H2O)</u>	<u>(in. H2O)</u>	<u>(cfm)</u>	<u>(cfm)</u>	<u>-</u>
<u>500</u>	<u>1</u>	<u>2</u>	<u>5</u>	<u>2.2</u>	<u>y</u>
<u>1000</u>	<u>2.5</u>	<u>2.5</u>	<u>10</u>	<u>2.5</u>	<u>y</u>
<u>2000</u>	<u>4</u>	<u>3</u>	<u>20</u>	<u>3.7</u>	<u>y</u>

This table shows the measured pressure, the added 1 in of pressure, and the calculated allowed 1% leakage. Taking the “Add 1 in.” pressure to the graph and reading the corresponding makeup air flowrate fills in this column. Comparing allowed leakage to makeup air determines whether the rig meets the specification. Note that, in this example, the pre-sealing values would also have met the requirements for this test.