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SAE RESTRAINT SYSTEMS EFFLUENT TEST PROCEDURE

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1. Scope

Scope—This SAE Recommended Practice describes a method to collect, identify, and quantify effluent resulting from deployment of in-vehicle stored energy restraint systems. Deployment and collection is completed in a 2.83 m^3 (100 ft^3) chamber. This procedure is written as a guideline for the identification and quantification of both particulate effluent (size, concentration, and composition) and gaseous effluent (concentration and composition). The intent of this procedure is to describe and recommend testing methods and not to establish limits for the effluent. This procedure should be used in conjunction with performance specifications from the customer and/or manufacturer of the device(s) being tested. This is a general procedure for repetitive and comparative testing, and suggests only general guidelines for the safe conduct of tests and reliable data correlation.

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J211—Instrumentation for Impact Tests
SAE J1538—Glossary of Automotive Inflatable Restraint Systems
SAE J1630—Driver of Passenger Airbag Module Deployment Test Procedure

3. ***General Test Requirements—***The deployment test equipment for performance and effluent testing shall provide a reliable, accurate, and repeatable testing method, adaptable for mounting various in-vehicle stored energy restraint systems.

3.1 Test Facility—Stored energy restraint systems are typically Department of Transportation classified. Therefore, facilities for conducting tests on pyrotechnic or stored gas devices must comply with all local and state building codes. A suitable floor plan and work area design is also very important for proper execution of tests. Features include a physical barrier between test personnel and the device being tested. An exhaust fan is recommended to vent gas and particulate from the test chamber and work area.

3.2 Safety Requirements—In consideration of safety for test personnel working with experimental devices, appropriate facilities and training must be provided. Examples of the necessary safety equipment include the following: remote deployment systems and equipment shielding for personnel, warning system (i.e., siren and/or light), and personal safety items such as lab coats or clothing, safety glasses, gloves, hearing protection, respirators, and grounding straps, if required. Proper written safety procedures should be followed in accordance with standard ordinance and pyrotechnic industry practice. In addition, each operator should be familiar with the hazards of the devices being tested and hazards of the effluent being evaluated. All general safety practices should be followed. Test chamber should be appropriately grounded and be constructed to preclude the buildup of static electricity. All applicable government safety and health standards (e.g., OSHA) must be followed.

3.3 Equipment List

3.3.1 FIXTURES AND SUPPORT EQUIPMENT

a. 2.83 m^3 (100 ft^3) chamber constructed of suitable noncorrosive metal (Figure 1)

   1. Sampling ports (for gas and particulate sampling)
   2. Mounting fixtures
   3. Expansion diaphragm or one-way exhaust vent

b. Temperature, pressure, and humidity indicators
c. Timer

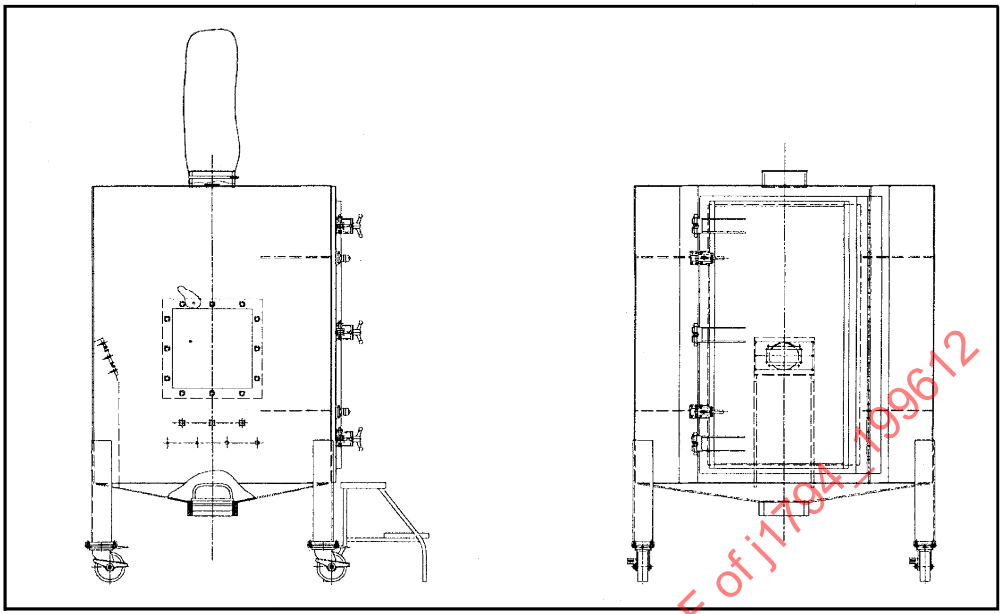

FIGURE 1—TYPICAL 2.83 m^3 (100 ft^3) CHAMBER

3.3.2 Sample Collection

a. Cascade impactor (Anderson Model One CFM Ambient Sampler or equivalent)
b. Single total particulate filter holder
c. Particulate filter (Pallflex 47 mm or equivalent)
d. Hermetic air sampling pump
e. Flowmeters
f. Inert sampling bag (Tedlar bag or equivalent)

3.3.3 Data Acquisition System (Optional)—Records and displays the internal bag and/or inflation device pressure versus time data.

3.3.4 Deployment Source—Provides the proper stimulus to actuate the inflator.

3.3.5 Sample Analysis (Standard Equipment)

a. Gas Analysis

1. Gas chromatograph
2. Fourier transform infrared spectrometer
3. Chemiluminescence analyzer
4. Direct reading indicator tubes

b. Particulate Analysis

1. Analytical balance
2. Atomic emission or atomic absorption spectrometer
3. Ion chromatograph
4. Acid/base titrator
5. pH meter

3.3.6 SAMPLE ANALYSIS (USEFUL AUXILIARY EQUIPMENT)

a. Gas Analysis

1. Gas chromatograph/mass spectrometer
2. Non-dispersive infrared analyzers
3. Electrochemical analyzers
4. Ultraviolet-visible spectrometer

b. Particulate Analysis

1. X-ray fluorescence spectrometer
2. X-ray diffraction instrument
3. High-performance liquid chromatograph
4. Mass spectrometer
5. Air circulating oven and temperature conditioning chamber

4. Equipment Specifications

4.1 Fixtures and Support Equipment

4.1.1 Test chamber shall have a volume of 2.83 m^3 (100 ft^3) ± 5% inclusive of hardware and mounting fixtures. The chamber shall be capable of withstanding repeated deployment pressures and forces associated with deploying in-vehicle stored energy restraint systems. The chamber shall provide a sealable access door for test personnel and allow for easy cleaning. The chamber shall have a pressure relief mechanism, i.e., an expansion diaphragm or one-way exhaust vent.

4.1.2 Mounting fixtures shall allow for the easy, but secure, attachment of the test assemblies in accordance with the intent of the test.

4.1.3 Temperature indicator should be capable of 1 °C resolution at the test temperature. Humidity indicator should be capable of 2% relative humidity (RH) resolution and have a range of 25% RH to 75% RH. Both the temperature and humidity indicators should be calibrated using SAE recommended practices.

4.1.4 Timer shall be capable of measuring 1 s intervals.

4.2 Sample Collection

4.2.1 Cascade impactor shall utilize impactor disks and use a stainless steel 47-mm diameter filter holder as a back-up filter device. One 47-mm diameter particulate filter is required for the back-up filter assembly. (Typical filter characteristics: >99% efficient for 0.5 µm at 15 L/min.)

4.2.2 Single total particulate filter holder shall be 47-mm diameter aluminum and shall be fitted with one 47-mm diameter particulate filter. Impactor and filter holder shall be properly grounded.

4.2.3 Hermetic air sampling pump shall be capable of 28.32 L/min (1 ft^3/min) minimum flow rate.

4.2.4 Two types of flowmeters are required, one calibrated 0 to 50 L/min (0 to 2 ft^3/min) and one calibrated 0 to 10 L/min (0 to 0.4 ft^3/min). Flowmeters used shall measure volume directly, i.e., dry gas meter, bubble flowmeter, or other positive displacement flowmeter. Rotometers, mass-flow controllers, and other devices based on heated filament detectors are not acceptable for volume determinations. Flowmeters used to measure total volume should have a NIST-traceable calibration.

4.3 Data Acquisition System—If applicable, a data acquisition system (SAE J211) shall be provided to measure and record pressure output versus time.

4.4 Deployment Source—An appropriate level and duration of deployment stimulus, as specified by the manufacturer or customer, should be used to deploy the device(s) being tested.

4.5 Analysis

4.5.1 Analytical balance should be capable of 0.1 mg resolution and must be equipped with an antistatic device.

5. Test Procedure

5.1 Test Setup

5.1.1 Clean chamber with mild soap and water. Rinse with water spray. Place circulating fan in front of chamber opening and air dry.

5.1.2 Using appropriate brackets and fixtures, mount the device(s) being tested inside the chamber.

5.1.3 Connect hermetic air sampling pump to flowmeter and route tubing into the test chamber. Flow rate should be measured using an appropriate flowmeter (see 4.2.4) on the exhaust side of the pump, near the sampling device.

5.1.4 Place desired particulate collection apparatus inside chamber and connect sample tubing. (See Section 6 for preparation.) Device(s) to be tested and particulate and gas sampling apparatus shall be placed in the location required by the requester or customer in order to achieve desired comparison. If location is not specified, the sampling apparatus shall be situated near the geometric center of the chamber. (Placing collection apparatus on the chamber floor is unacceptable.) Sampling apparatus must not interfere with deployment.

5.1.5 Calibrate the system flow rate by placing the required calibrated flowmeter at the inlet of the desired particulate collection apparatus and adjust the air sampling pump to match the required flow rate.

5.1.6 Test electrical resistance of device(s) to be tested with ohmmeter to ensure proper connection (as applicable).

5.1.7 Install desired temperature and humidity sensors into chamber. Condition chamber air to 22 °C ± 3 °C and <75% RH.

5.1.8 Ensure expansion diaphragm or one-way vent is installed properly and will remain air tight after initial pressure surge.

5.2 Deployment of Test Device(s)

5.2.1 Attach deployment leads to device(s) being tested (as applicable).

NOTE— Safety devices must render deployment actuation system inoperable during this connection step.

5.2.2 Close and secure door to chamber.

5.2.3 Clear all personnel from the testing area and deploy the device(s) to be tested.

5.3 Sample Collection

5.3.1 Start sampling pump and timer at time of deployment at flow rate required. Allow pump to draw particulate sample for the required time interval. In the absence of flow specifications, a flow rate of 5 L/min and a sampling time of 20 min is recommended for total particulate sampling. When sampling with an impactor in the absence of flow specifications, the manufacturer's specifications should be followed. Check flowmeter periodically to ensure proper flow is maintained. Duration of the test should be consistent with the impactor load limits and required flow rate for the type of particulate collection apparatus. If the flow rates measured at the beginning and end of particulate sampling differ by more than 10% particulate sample data shall be rejected (unless impactor manufacturer specifies otherwise and accurate flow corrections can be made).

5.3.2 Measure the atmospheric pressure and temperature near the flow measurement device. These measurements will later be used to make volume corrections (see 6.1.4).

5.3.3 Connect clean, empty, inert sampling bag to exhaust tubing from sampling pump and fill with chamber gas. Prior to filling the bag, gas lines and pump should be purged adequately to guarantee that the sampled gas is actually from the test tank and not sample line dead volume. For some testing, chamber gases may be pumped directly into analysis cells.

NOTE— Gas samples may be pulled from the chamber at desired time intervals in order to fulfill designated requirements. Sampling times should be carefully recorded, as these times may affect chemical composition and dilution caused by sampling. If gas sampling time intervals exceed particulate sampling time intervals, a separate pump and sampling system may need to be plumbed into the 2.83 m^3 (100 ft^3) chamber. If continuous sampling is done for long periods of time or if numerous samples are collected, the effects of dilution on the test chamber gases and particulate as a function of time must be taken into account.

5.3.4 Turn off sampling pump(s) at appropriate time interval(s) and open chamber door. Allow remaining chamber effluent to be vented away safely.

5.3.5 Remove particulate collection apparatus and device(s) being tested. Refer to Section 6 for handling of particulate apparatus.

6. Particulate Analysis—Two methods are presented in this procedure for the collection of particulate. The first method discusses measuring total particulate, and the second method describes measurement of the particle size distribution. Chemical analysis can be performed along with either particulate collection method. The method used is based upon the discretion of the requestor and/or the desired data.

Particulate analysis methods require weighing of filters, impactor plates, etc. Masses should all be recorded in mg and measured to 0.1 mg, and concentrations should be recorded in mg/m^3. Prior to weighing, objects must always be equilibrated to constant mass at ambient conditions. Balance must reach a stable mass before a mass is recorded.

6.1 Total Particulate Method—This method of sample collection utilizes a single filter to collect a sample representing the total particulate of the deployment device(s) being tested.

6.1.1 Weigh new filter.

6.1.2 Assemble filter into filter holder apparatus.

6.1.3 After collection (see 5.3), disassemble filter holder and reweigh filter.

6.1.4 Calculation of Total Particulate Concentration:

a. Subtract initial tare mass from post-deployment mass. Record this value as Total Particulate Mass (in mg).
b. Multiply the average flow rate (L/min) by the sampling time (min). Record as Total Volume Gas (L). If the total volume was measured directly, this measured volume may be used here. Correct volume to a standard temperature of 22 °C and pressure of 101 325 Pa (1 atm). Record as Total Corrected Volume of Gas.
c. Divide Total Corrected Volume Gas by 1000 in order to convert to Total Corrected Cubic Meters of Gas.
d. Divide Total Particulate Mass by Total Corrected Cubic Meters of Gas and report Total Particulate Concentration in mg/m^3.
e. Equation 1 summarizes 6.1.4 calculations:

$$\text{Tot Part Conc}\left(\frac{\text{mg}}{\text{m}^3}\right) = \frac{\text{Tot Part Mass (mg)}}{\left[\text{Avg Flow}\left(\frac{\text{L}}{\text{min}}\right)\right]\left[\text{Samp Time (min)}\right]\left[\frac{\text{Pres(Pa)}}{101,325\text{(Pa)}}\right]\left[\frac{295(°\text{K})}{\text{Temp}(°\text{K})}\right]\left[\frac{1(\text{m}^3)}{1000(\text{L})}\right]} \qquad \text{(Eq. 1)}$$

where:

Tot = Total
Part = Particulate
Conc = Concentration
Avg = Average
Samp = Sampling
Pres = Atmospheric Pressure
Temp = Room Temperature

f. See 6.3 for chemical analysis instructions, if applicable.

6.2 Particle Size Distribution Method—This method of sample collection utilizes a cascade impactor to collect particulate of specific size ranges for quantitative analysis of the particle size distribution and size-dependent chemical composition.

6.2.1 Weigh the impactor discs for each individual stage and for the particulate back-up filter, and record the Tare Masses.

6.2.2 Assemble the impactor according to manufacturer specifications.

6.2.3 After collecting the particulate sample (see 5.3), disassemble impactor, reweigh the impactor discs and back-up filter, and record masses as Gross Masses.

6.2.4 Calculation of Particle Size Distribution:

a. Subtract the Tare Mass from the Gross Mass of each impactor disc and back-up filter to obtain the Net Masses.
b. The sum of the Net Masses for all the fractions represents the Total Impactor Particulate Mass (in mg) for the sample. The sum of the masses for the back-up filter and those discs designated by the impactor manufacturer as “respirable” fractions represent the respirable mass (in mg) of the sample.
c. Due to losses of particulate on the impactor walls during sampling, it is not correct to calculate airborne particulate size distributions directly by dividing the individual Net Masses by the sampled gas volume. Instead, relative mass distributions are first calculated by dividing each desired Net Mass (or range of Net Masses) by the Total Impactor Particulate Mass. Multiplying these relative mass distributions by the Total Particulate Concentration determined in 6.1 then yields the Corrected Particulate Concentrations as a function of size.

d. Equation 2 summarizes 6.2.4 calculations:

$$\text{Corr Part Conc (mg/m}^3) = \frac{\text{Net Mass(es)(mg)}}{\text{Tot Impactor Mass (mg)}} \text{Tot Part Conc (mg/m}^3) \qquad \text{(Eq. 2)}$$

where:

Corr = Corrected
Part = Particulate
Conc = Concentration
Tot = Total

6.2.5 See 6.3 for chemical analysis instructions, if applicable.

6.2.6 Impactor and discs must be thoroughly washed and dried before their next use.

6.3 Chemical Analysis of Particulate—Particulate collected by either the total particulate method or the size-dependent particulate method may be chemically analyzed. As specified, samples from different particulate size ranges may also be combined for chemical analysis. Accordingly, the chemical analyses described in this section may pertain to any of these assorted particulate sample types. For these procedures, dissolution and filtering should be designed to maximize particulate collection efficiencies and minimize filtrate dilution volumes.

6.3.1 Place samples (e.g., the total particulate sample, the impactor disc(s), and/or the back-up filter) in separate filter funnels, equipped with inert filters, capable of trapping insoluble particulate. Quantitatively wash the samples with de-ionized water and collect and label filtrates.

6.3.2 Additional solvent washes may be done as specified. For example, the water-insoluble samples are frequently quantitatively washed with acid. Filtrates are collected in fresh volumetric flasks and labeled.

6.3.3 The various fractions should then be analyzed for the requested constituents (e.g., cations, anions, metals, hydronium or hydroxide, etc.). Instrumentation may include a pH meter, ion chromatograph, acid/base titrator, atomic emission spectrometer and any other instrumentation or methodology configured to achieve the quantification of the requested components. The methods used must be recognized standard methods, and must be calibrated within the expected concentration ranges using NIST-traceable standards (when available).

6.3.4 CALCULATION OF CHEMICAL CONCENTRATIONS FOR PARTICULATE COLLECTED USING THE TOTAL PARTICULATE METHOD—Multiply the analytical concentrations (mg/L) derived for the various chemical species (see 6.3.3) by the pertinent particulate wash volumes (L) (water-soluble, acid-soluble, etc.) to obtain the Chemical Masses (mg). Divide the Chemical mass by the Total Corrected Cubic Meters of Gas (see 6.1.4.b and 6.1.4.c) to obtain the Chemical Concentration (mg/m^3), i.e., Equation 3:

$$\text{Chem Conc (mg/m}^3) = \frac{[\text{Anal Conc (mg/L)}][\text{Wash Vol (L)}]}{\text{Tot Corr Cubic Meters Gas (m}^3)} \qquad \text{(Eq. 3)}$$

where :

Chem = Chemical
Conc = Concentration
Anal = Analytical
Vol = Volume
Tot = Total
Corr = Corrected

In order to calculate a detection limit (mg/m^3) that corresponds directly to a Chemical Concentration, the detection limit for the specific analytical technique utilized in 6.3.3 must first be accurately measured using accepted methods. This detection limit must then be multiplied by the pertinent particulate wash volume and then divided by the Total Corrected Cubic Meters of Gas. A detection limit, therefore, will depend not only upon the chemical analysis method, but also upon the wash volume and gas volume sampled.

6.3.5 CALCULATION OF CHEMICAL CONCENTRATIONS FOR PARTICULATE COLLECTED USING THE SIZE DISTRIBUTION METHOD—Determine the Chemical Mass (mg) of a requested constituent in a given fraction (water-soluble, acid-soluble, or other solubles from impactor stages or filters) by multiplying the analytical concentrations (mg/L) (see 6.3.3) by the fraction's volume (L). To accurately reference this Chemical Mass to the correct volume of gas, which orginally contained the particulate, divide the Chemical Mass by the Total Impactor Particulate Mass (see 6.2.4.b), and then multiply by the Total Particulate Concentration (see 6.1.4.d). This correction is required to account for loss of particulate inherent to impactor sampling. When reporting these Chemical Concentrations (mg/m^3), in order to avoid confusion, always associate a Chemical Concentration with the sample to which it pertains (e.g., iron concentration for acid-soluble components of the 0.5 to 1.0 µm particle size range). These calculations are summarized in Equation 4:

$$\text{Chem Conc (mg/m}^3) = \frac{[\text{Anal Conc (mg/L)}][\text{Fraction Volume (L)}][\text{Tot Part Conc (mg/m}^3)]}{\text{Tot Impactor Part Mass (mg)}} \quad \text{(Eq. 4)}$$

where:

Chem = Chemical
Conc = Concentration
Anal = Analytical
Vol = Volume
Tot = Total
Part = Particulate

In order to calculate a detection limit (mg/m^3) that corresponds directly to a Chemical Concentration in this case, the detection limit for the specific analytical technique utilized in 6.3.3 must first be accurately measured using accepted methods. This detection limit must then be multiplied by the pertinent particulate wash volume, divided by the Total Impactor Particulate Mass, and then multiplied by the Total Particulate Concentration. A detection limit in this case, therefore, will depend not only upon the chemical analysis method, but also upon the wash volume, the impactor particulate losses, and the gas volume sampled.

7. Gas Analysis—Selection of analysis methods for gaseous effluent depends on how well the gases have been characterized for the device being tested. Analysis of gaseous effluent having unknown gas makeup requires full characterization of gases as described in 7.1. Gas concentrations should be expressed as a percentage or in parts per million (volume to volume).

7.1 Gas Analysis for Devices Requiring Gas Characterization—For gas samples that have not been previously characterized, careful qualitative analysis should precede quantitative analysis. The gas matrix should be well understood and interference effects should be properly accounted for before gases are quantified. Instrumentation useful for performing such analyses is listed in 3.3.5 and 3.3.6. Once gases in the effluent have been identified, quantitative analysis can be performed. Quantitative methods must be calibrated over the concentration ranges at which the gases being quantified are present. If concentration limits have been established for compounds, where possible, the calibration should span at least 1/3 to 3 times the limit requested. Gas concentrations below measured detection limits or above upper calibration standards shall be reported as less than detection limits or greater than upper calibration limit. NIST-traceable gas standards should be used in calibration models. When NIST-traceable gas standards are not available, gas standards may be manufactured using accepted alternative processes. When first developing calibration models, it is recommended that alternate methods be used to confirm analytical results. Refer to Appendix A for suggested analysis methods for various gases. Appendix A is not meant to provide a complete list of the gases generated by restraint systems. It is the responsibility of the manufacturer to properly identify, quantify, and report the gases present in the effluent.

7.2 Gas Analysis for Devices with Previously Characterized Gases—The gas sample should be analyzed for the required gas compounds using Fourier transform infrared spectrometry and/or other accepted methods (see 3.3.5, 3.3.6, and Appendix A). Calibration models should be carefully set up for quantifying the established gas effluent from inflation devices (see 7.1). Sampling and analysis times should be carefully recorded (see 5.5.3).

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