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Australian/New Zealand Standard™

Methods for sampling and analysis of ambient air

Method 9.11: Determination of suspended particulate matter—PM_{10} beta attenuation monitors

PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EV-007, Methods for Examination of Air, to supersede AS/NZS 3580.9.11:2008.

The objective of this Standard is to provide regulatory and testing bodies with a method for continuously monitoring suspended particulate matter with an equivalent aerodynamic diameter (EAD) of less than 10 µm in ambient air, providing near real-time measurement of mean particle concentration. This is one in a series of Standards for the determination of particulate matter in ambient air.

During the preparation of this Standard, the Committee again paid attention to ISO 10473:2000, *Ambient air—Measurement of the mass of particulate matter on a filter medium—Beta-ray absorption method*, but this was not adopted as some commonly used instruments fall outside its scope.

The requirements for instruments specified in this Standard were derived from those given in the United States Environmental Protection Agency (US EPA) *Code of Federal Regulations*, Title 40 Protection of Environment, Part 53 'Ambient air monitoring reference and equivalent methods', (40 CFR 53) Subpart B, 'Procedures for Testing Performance Characteristics of Automated Methods for SO_2, CO, O_3, and NO_2'.

Instruments bearing the US EPA equivalency designation predominate in Australia and New Zealand. Accordingly, it was deemed appropriate to accept the US EPA designation of instruments with minor modifications for local requirements where necessary. The US EPA definitions for performance characteristics vary considerably in presentation (if not in substance) from those currently prescribed in ISO 9169:2006, *Air quality—Definition and determination of performance characteristics of an automatic measuring system*, but have nevertheless been retained, for the sake of preserving consistency with US EPA.

The term 'normative' has been used in this Standard to define the application of the appendix to which it applies. A 'normative' appendix is an integral part of a Standard.

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METHOD

1 SCOPE

This Standard sets out the method for the determination of suspended particulate matter in ambient air using a beta attenuation monitor (BAM). This method can provide a measure of the time-integrated mean particle concentrations for periods ranging from 10 min to 24 h. Measurements made in accordance with this method, when averaged over a 24-hour period, are considered to be equivalent to those determined in accordance with US EPA *Code of Federal Regulations*, Title 40 Protection of Environment, Part 53 'Ambient air monitoring reference and equivalent methods', Subpart D, 'Procedures for Testing Performance Characteristics of Methods for PM_{10}'.

2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS ISO/IEC
17025 General requirements for the competence of testing and calibration laboratories

AS/NZS
3580 Methods for sampling and analysis of ambient air
3580.1.1 Method 1.1: Guide to siting air monitoring equipment

ISO/IEC
Guide 98-3:2008 Uncertainty of measurement—Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

EN
12341 Ambient air—Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2,5}$ mass concentration of suspended particulate matter

US EPA
40 CFR 53 Code of Federal Regulations, Title 40 Protection of Environment, Part 53 Ambient Air Monitoring Reference and Equivalent Methods, Subpart D Procedures for Testing Performance Characteristics of Methods for PM_{10}

NEPC
Environment Protection and Heritage Council, Peer Review Committee (PRC)

National Environment Protection (Ambient Air Quality) Measure, Technical Paper No. 5, Data Collection and Handling, 2001

3 DEFINITIONS

For the purposes of this Standard, the definitions below apply.

3.1 Areic

Modifier used to denote an attribute divided by area.

3.2 Beta ray

Radiation emitted by electrons during the nuclear decay of radioactive elements. Monitors used in compliance with this method typically use an element such as Carbon 14 (^{14}C).

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3.3 Equivalent aerodynamic diameter (EAD)

The diameter of a spherical particle of unit density 1 g/cm^3 which exhibits the same aerodynamic behaviour as the particle in question.

3.4 PM_{10}

Suspended particulate matter consisting of particles having an EAD of less than 10 µm, which is passed by a size classifier having performance characteristics as defined in US EPA 40 CFR 53 Subpart D.

3.5 Range

Nominal minimum and maximum concentrations that a method is capable of measuring. The nominal range is specified by the lower and upper range limits in concentration units, e.g. 0 to 10 000 micrograms per cubic metre (µg/m^3).

3.6 Uncertainty

A variable associated with the result of a measurement that characterizes the dispersion of the values that could be reasonably attributed to the measurand.

NOTE: The variable may be, for example, a standard deviation (or given multiple of it), or the half-width of an interval having a stated level of confidence. ISO/IEC Guide 98-3 provides a basis of evaluating uncertainty in the output of a measurement system.

4 PRINCIPLE

4.1 Principle of measurement

When the high-energy electrons emanating from the radioactive decay of a suitable source such as Carbon 14 (^{14}C) or Krypton 85 (^{85}Kr) interact with nearby matter they lose energy and, in some cases, are absorbed by the matter. These high-energy electrons emitted through radioactive decay are known as beta rays and the process is known as beta ray attenuation. When matter is placed between the radioactive source and a device designed to detect beta rays, the beta rays are absorbed and/or their energy diminished. This results in a reduction in the number of beta particles detected.

The magnitude of the reduction in detected beta particles is a function of the mass of the absorbing matter between the beta source and the detector. The number of beta particles passing through absorbing matter, such as particulate matter deposited on a filter media, decrease nearly exponentially with the mass through which they pass. Equation 4.1(1) (Empirical Absorption Law or Lenard's Law) shows this relationship:

$$I = I_0 \, .e^{-km} \qquad \ldots 4.1(1)$$

where

I = number of incident electrons per unit of time (counts per second). (The measured beta ray intensity, of the attenuated beta ray—particle laden filter media)

I_0 = number of incident electrons per unit of time (counts per second). (The measured beta ray intensity of the unattenuated beta ray—clean filter media)

k = coefficient of absorption per unit mass (cm^2/mg). (The absorption cross-section of the material absorbing the beta rays)

m = areic mass of matter encountered by the beta radiation (mg/cm^2). (The mass density of the absorbing matter)

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Practically, it is not necessary to determine I_0 and the areic mass of the collected particulate matter is determined as follows:

(a) *Step one*: a measurement is made on a blank filter:

$$I_1 = I_0 \,.e^{-km_0} \qquad \text{. . . 4.1(2)}$$

where

I_1 = number of electrons transmitted per unit of time (counts per second) measured after the filter

m_0= areic mass (mg/cm^2) of the blank filter

(b) *Step two*: a measurement is made on the same filter loaded with particulate matter:

$$I_2 = I_0 \,.e^{-k\,(m_0 + \Delta m)} \qquad \text{. . . 4.1(3)}$$

where

I_2 = number of electrons transmitted per unit of time (counts per second) measured after the filter loaded with particulate matter

Δm= areic mass (mg/cm^2) of particulate matter collected on the filter

Combining Equations 2 and 3:

$$I_1 = I_2 \,.e^{+k\Delta m} \qquad \text{. . . 4.1(4)}$$

$$\Delta m = \frac{1}{k} \ln \frac{[I_1]}{[I_2]} \qquad \text{. . . 4.1(5)}$$

NOTE: The Empirical Exponential Law (Equation 1) is valid in the practical working range. There is, however, an upper limit that is directly proportional to the maximum energy of the emission spectrum of the beta source used.

4.2 Limitations and interferences

Errors in mass determination can be caused by irregularities in the spatial distribution of the stream of beta electrons and heterogeneous deposits of particulate matter due to a deterioration of the sampling system.

Changes in atmospheric pressure and temperature cause the density of air between the source and the detector to change. This can affect the determination of the mass of particulate matter deposited on the filter. The error can be minimized by keeping the time between the measurement of I_1 and I_2 as short as possible and can be corrected by measuring the atmospheric pressure and temperature, or by use of a dual detection system; in the latter case, the result of the second measurement (I_2) has to be recorded continuously as mass accumulates over time.

The elemental and chemical composition of atmospheric particulate matter has a small effect on the value of the coefficient of absorption per unit of mass (k). The k value depends on the maximum energy of the beta radiation therefore its value depends on the radioactive isotope used.

The effect of radioactivity in particulate matter is negligible for long-lived radioisotopes. However, in locations where low levels of radon and its daughters are present, the response of beta gauges may be affected. Some BAMs have inbuilt systems to correct for this type of interference. The magnitude of the error depends on the type of equipment used.

In some sampling climates (high humidity and/or temperature), there is the potential for water to condense on the filter media causing artificially high readings. The use of a sample inlet heater can mitigate this problem; however, care needs to be taken to ensure the sample is not excessively heated so as to lose semi-volatile compounds in the particulate matter.

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4.3 Types of beta attenuation monitors (BAMs)

4.3.1 *General*

There are two basic methods of operation of BAMs which utilize this principle of measurement:

(a) Step-wise.

(b) Continuous.

4.3.2 *Step-wise*

Step-wise BAMs make a 'zero' measurement of the initial amount of attenuation on a blank spot of filter media. This same spot is then moved to a suitable sampling position where it is used to collect particles at a known sampling flow rate and predetermined time period (typically 1 h). At the end of the sampling period the now loaded filter spot is moved either to the original or a second beta source and detector where the amount of attenuation through the loaded filter is measured. The accumulated areic mass for each sampling period, e.g. 1 h, can then be calculated using Equation 4.1(5) above.

4.3.3 *Continuous*

Continuous BAMs measure the mass of particles effectively in real-time as they accumulate on the filter during the sampling process. A single filter spot is used during the measurement cycle, which takes place in a chamber that is used for both particulate matter collection and measurement. After an initial 'zero' measurement on the filter spot, air is sampled at known flow rate and particles accumulate on the same spot for a pre-determined time period (maximum 24 h). During this time, the amount of particulate matter loading, as determined by the amount of change in beta attenuation, is continuously measured (every 1–4 s). Using this measurement of mass per unit of time, the accumulated areic mass can then be calculated using Equation 4.1(5) to provide continuous results of PM_{10} as they change in real-time.

5 APPARATUS

5.1 General

Figure 1 shows the main components of a typical BAM.

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