Compendium of Methods
for the Determination of
Inorganic Compounds
in Ambient Air

Chapter IO-1

CONTINUOUS MEASUREMENT OF PM$_{10}$ SUSPENDED PARTICULATE MATTER (SPM) IN AMBIENT AIR

OVERVIEW

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OVERVIEW

Under authority granted in Section 109 of the Clean Air Act (the Act) and its amendments, the U. S. Environmental Protection Agency (EPA) has promulgated primary and secondary national ambient air quality standards (NAAQS) for six criteria pollutants: SO$_2$, NO$_x$, CO, O$_3$, PM$_{10}$/PM$_{2.5}$, and Pb. These primary (health-related) and secondary (welfare-related) pollutant standards are contained in Title 40, Part 50 of the Code of Federal Regulations (40 CFR 50). The reference methods for monitoring ambient atmospheres for these criteria pollutants are in the Appendices of 40 CFR 50, A through G.

Section 109 of the Act requires the EPA to evaluate, at 5-year intervals, the criteria for which standards have been promulgated and to issue any new standards as may be appropriate.

The issuance of reference methods designed to monitor these criteria pollutants has a legal basis in Section 301 of the Act, which states that the regulations necessary to carry out the provisions of the Act may be promulgated by the Administrator. To evaluate and ascertain the status of air quality with regard to the criteria pollutants, uniform analytical methods are used to ensure consistency and accuracy in the data generated.

Suspended particulate matter (SPM) in air generally is considered to be all airborne solid and low vapor pressure liquid particles. Suspended particulate matter in ambient air is a complex, multi-phase system consisting of a spectrum of aerodynamic particle sizes ranging from below 0.01 μm to 100 μm and larger. Historically, particulate matter (PM) measurement has concentrated on total suspended particulates (TSP), with no preference to size selection. The EPA's approach toward regulating and monitoring TSP matter has evolved over time. When EPA first regulated TSP, the NAAQS was stated in terms of particulate matter captured on a filter with an aerodynamic particle size of < 100 μm as defined by the TSP sampler. In 1987, the primary standard for TSP was replaced with a PM$_{10}$ standard, which includes only particles with an aerodynamic diameter of 10 μm or less. Then, in 1997, the primary standard for PM$_{10}$ was replaced with a PM$_{2.5}$ standard. This standard was promulgated because the EPA now has interest on "respirable" particles (< 2.5 μm), those particles small enough to be drawn into and deposited in the respiratory system. Particles in this size range can have direct health effects. The depth to which these particles can penetrate the respiratory system as a function of particle size is shown in Figure 1.

Respirable particles are attributed to growth of particles from the gas phase and subsequent agglomeration; most coarse particle (sizes 2.5-10 μm) are made of mechanically abraded or ground particles. Particles that have grown from the gas phase, either because of condensation, transformation, or combustion, occur initially as very fine nuclei (0.05 μm). These particles tend to grow rapidly to accumulation mode particles around 0.5 μm which are relatively stable in the air. Coarse particles, on the other hand, are mainly produced by mechanical forces, such as crushing and abrasion. These coarse particles therefore normally consist of finely divided minerals, soil, or dust that result from entrainment by the motion of air or from other mechanical action within their area. Since the mass of these particles is normally > 3 μm, their retention time in the air parcel is shorter than that of the fine particle fraction.

As illustrated in Figure 1, these smaller particles penetrate deeply into the lung, where the potential for health effects is the greatest. In addition, the smaller particles typically are man-made. TSP typically has a bimodal distribution, with naturally occurring particles centered at about 10 μm and man-made particles centered at about 0.4 μm (as illustrated in Figure 2).

Sampling options for PM_{10} compliance monitoring fall into two categories: "reference" methods and "equivalent" methods. This Chapter, IO-1, "Continuous Measurements of Suspended Particulate Matter (SPM) in Ambient Air," contains the equivalent methods approved for real-time monitoring of PM_{10} mass loading. Chapter IO-2, "Integrated Sampling of SPM," contains the reference methods. The equivalent methods for PM_{10} presented in this chapter are instrumental and provide continuous measurements of ambient PM_{10} concentration. Instruments using two different measurement principles have received EPA's approval as equivalent methods: The first uses beta-radiation; the second uses an oscillating pendulum. Unlike the reference methods, the equivalent methods allow concentrations to be tracked in real-time. This property is useful when parameters such as the diurnal variation in concentration or the change in concentration associated with certain activities are of interest.

The beta attenuation monitor samples at ambient temperatures, relative humidities, and gas concentrations to minimize particle volatilization biases. These monitors operate at a low-volume flow rate (nominally 16.7 liters/minute [L/min]) using either a virtual impact or cyclonic flow operating principal to determine the 50% cut-point. For beta attenuation monitors, low-energy beta rays (i.e., 0.01-0.1 MeV electrons) are focused on deposits on a filter tape and attenuated according to the approximate exponential function of particulate mass (i.e., Beer's Law). These automated samples employ a continuous filter tape. Typically, the attenuation through an unexposed portion of the filter tape is measured, and the tape is then exposed to the ambient sample flow where a deposit is accumulated. The beta attenuation is repeated, and the difference in attenuation between the blank filter and the deposit is a measure of the accumulated concentration. Blank corrected attenuation readings can be converted to mass concentrations for averaging times as short as 30 minutes. While these monitors are capable of producing half-hourly average mass concentrations, 24-hour averaging period is required for typical ambient concentrations to obtain sufficient particulate deposition for an accurate determination.[1] The two types of beta-gauges are the Andersen Beta-Gauge (Method IO-1.1) and the Thermo Environmental, Inc. (formally Wedding and Associates) Beta-Gauge (Method IO-1.2).

The Andersen monitor directly measures particulate mass at concentrations of 0.005-20 mg/m^3 on a real-time basis. With certain specifications, the Andersen instrument has been designated as an equivalent method for determining 24-hour average PM_{10} concentration in ambient air by the EPA under Designation No. EQPM-0990-076, effective September 18, 1990. The monitor described in Method IO-1.1 presents the configuration and operation of the instrument as an equivalent method for PM_{10}.

With the Andersen instrument, ambient air enters the monitor through a PM_{10} inlet head at a flow rate volume of 16.7 L/min. The air containing PM_{10} enters the instrument where it is pulled through the glass fiber filter tape, and the particles are deposited on the tape. Low level beta radiation is emitted from a stainless steel capsule, containing Krypton-85 gas, towards the filter tape containing deposited PM_{10}. The particle matter on the tape reduces the intensity of the beta radiation reaching the measuring chamber on the opposite side of the tape. To compensate for the effect of the filter tape on the reduction of the level of beta radiation, the source directs a second beam of beta particles through a "foil" that mimics clean filter tape to a second measuring chamber (compensation chamber). No air flow is directed to the compensation foil so the effect of the foil on the beta radiation intensity remains constant. The instrument compares the measurement of the compensation foil to the measurement of the filter tape with deposited PM_{10} to determine the mass of the particulate matter. Because changes in temperature, pressure, or humidity can affect PM_{10} measurement on the filter tape, the measurements made through the compensation foil are impacted to the

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[1]Chow, J.C., "Measurement Methods to Determine Compliance with Ambient Air Quality Standards for Suspended Particles," *J. Air & Waste Manage. Assoc.*, Vol. 45: 320-382, 1995.

same degree. The foil measurements provide baseline data to compensate for these meteorological effects.
This monitor is less sensitive to temperature, pressure, and humidity fluctuations than some other types of
continuous particle monitors because the compensation foil measurements provide baseline data. Because
the measuring mechanism lacks moving parts, the instrument is not as sensitive to vibrational effects as other
types of continuous particulate monitors.

The Andersen monitor has certain limitations or interferences. In high-humidity or rainy climates, water
may collect on the filter tape and cause artificially high mass readings. In these same climates where the
instrument is housed in an air-conditioned environment, the ambient air inlet tube should be insulated to avoid
condensation or the inlet tube should be heated to ensure that any water drawn into the unit is vaporized.

The Thermo Environmental, Inc. beta gauge operates under the same basic principles as the Andersen
monitor, but with some differences. This instrument was designated as an equivalent method for PM$_{10}$ by
the EPA under Designation No. EQPM-0391-081, effective March 5, 1991. The configuration and operation
of this instrument is described in Method IO-1.2. The Thermo monitor can measure ambient mass
concentration with a resolution of about 3 μg/m^3 for a 1-h sampling period. A constant volumetric flow rate
for the PM$_{10}$ inlet of 18.9 L/min is used compared to the 16.7 L/min for the Andersen unit. A major
difference between the two monitors is the beta source. The Thermo monitor uses a carbon-14 beta source
compared to Krypton-85 gas for the Andersen monitor. The carbon-14 source does not require a license by
the Nuclear Regulatory Commission, whereas the Krypton-85 does. Apparatus and operational differences
between the two instruments are described in Methods IO-1.1 and IO-1.2.

Different from the beta-gauges, the Rupprecht and Pataschnick (R&P) PM$_{10}$ monitor is based upon a
tapering element oscillating microbalance (TEOM®) as a filter-based measurement system to continuously
measure particulate mass at concentrations between 5 μg/m^3 and several g/m^3 on a real-time mass monitoring
basis. The instrument calculates mass rate, mass concentration, and total mass accumulation on exchangeable
filter cartridges that are designed to allow for future chemical and physical analysis. In addition, this
instrument provides for hourly and daily averages. This system operates on the principal that particles are
continuously collected on a filter cartridge mounted on the tip of a tapered hollow glass element. The element
oscillates in an applied electric field. With this monitor, particle-laden air enters through an air inlet and then
passes to the sensor unit containing the patented microbalance system. The inlet system is equipped with a
sampling head to pre-separate particles at 10 μm diameter. The R&P PM$_{10}$ inlet is designed to allow only
particulate matter #10 μm in diameter to remain suspended in the sample air stream as long as the flow rate
of the system is maintained at 16.7 L/min. The monitor can also be operated as a TSP monitor or as a PM$_{2.5}$
monitor by changing the inlet head.

In operation, the sample stream passes into the microbalance system, which consists of a filter cartridge
(½ inch diameter) and oscillating hollow tube, where the stream is heated to a predetermined temperature.
The filter cartridge is a ½ inch diameter thin aluminum base (foil-like) assembly. A water resistant plastic
cone, which fits onto the oscillating element, is attached to the aluminum base. An automatic flow controller
pulls the sample stream through the monitor at flow rates between 0.5 and 5 L/min. The wider end of the
hollow element is fixed to a platform and is vibrated at its natural frequency. The oscillation frequency of
the glass element is maintained based on the feedback signal from an optical sensor.

As mass accumulates on the filter cartridge, the resonant frequency of the element decreases, resulting
in a direct measurement of inertial mass. Based upon the direct relationship between mass and frequency,
the monitor's microcomputer calculates the total mass accumulation on the filter and the mass rate and mass
concentration in real-time.

The TEOM® monitor is very sensitive to mass concentration changes and can provide precise measurements for sampling durations of 1-h or less. To achieve this level of precision, the hollow glass element must be maintained at a constant temperature to minimize the effects of thermal variations. Because the instrument's primary operating mechanism is the microbalance system, the instrument should be isolated from mechanical noise and vibration. The operating temperature of the element can be lowered to minimize the potential particle loss bias for more volatile compounds but must be maintained above the maximum ambient temperature encountered during the field sampling. The tapered element oscillating microbalance is discussed in detail in Method IO-1.3.
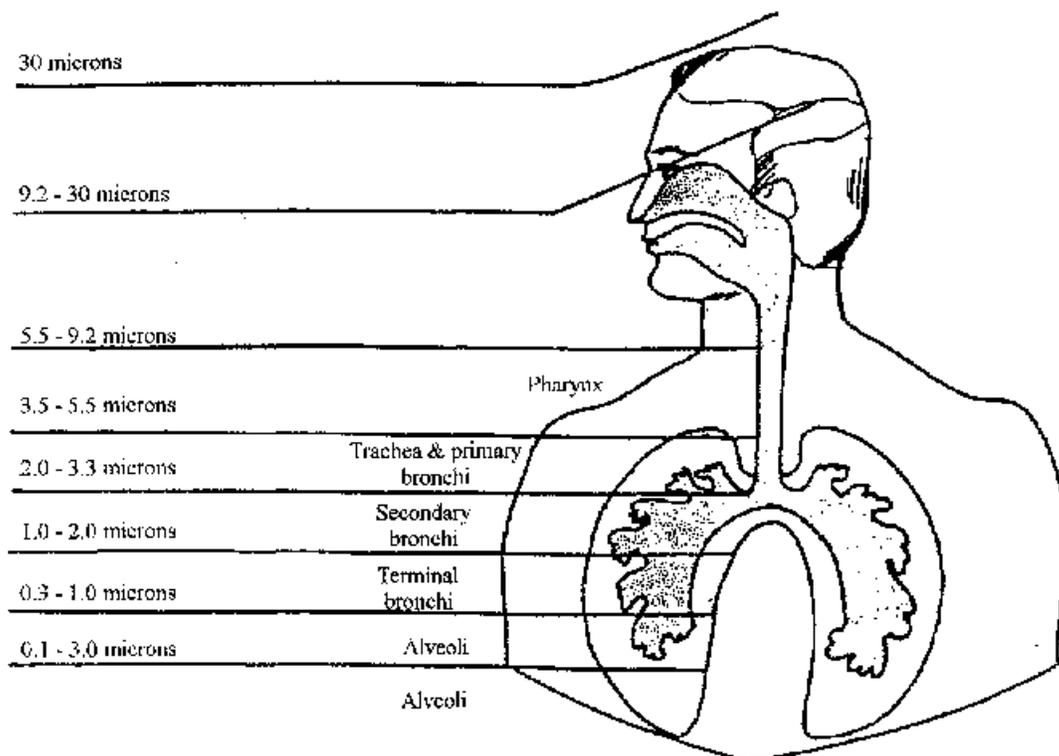
Figure 1. Example of the depth of respiratory system penetration based on particle size.

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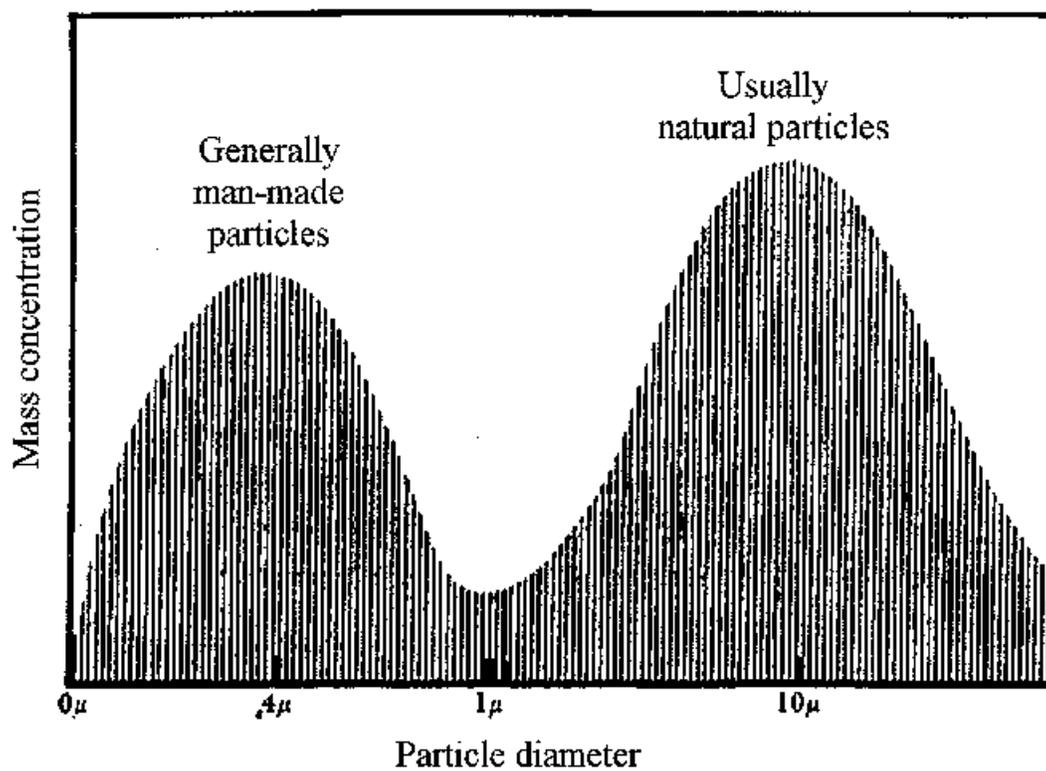Source: U.S. EPA, Air Pollution Training Institute (APTI), Course No. 435.

Figure 2. Example of bimodal distribution of particles in the atmosphere.

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Source: U.S. EPA, Air Pollution Training Institute (APTI), Course No. 435.