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Project Summary

Application Guide for Source PM_{10} Measurement with Constant Sampling Rate

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This manual presents a method, Constant Sampling Rate (CSR), which allows determination of stationary source PM_{10} emissions with hardware similar to that used for Methods 5 or 17. The operating principle of the method is to extract a multipoint sample so that errors due to spatial variation of particle size and anisokinetic sampling are kept within predetermined limits. Current specifications were designed to limit error due to spatial variations to 10%. The maximum allowable error due to anisokinetic sampling is ±20%; in essentially all sampling situations, cancellation of sampling error will limit overall anisokinetic sampling error to much less than this value.

This manual specifically addresses the use of the CSR methodology for determination of stationary source PM_{10} emissions. Material presented in this manual includes: calibration of sampling train components, pretest setup calculations, sample recovery, test data reduction, and routine equipment maintenance.

This Project Summary was developed by EPA's Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

To ensure that a representative sample of particulate matter is obtained from a flowing gas stream, three key factors must be considered. First, the length of the sampling period must be adequate to formulate an appropriate temporal average of stream conditions. Second, the location and number of sampling points must be chosen so that a spatial average of emissions across the sampling plane is obtained. Finally, sampling must be performed isokinetically so that the sample is not biased with respect to particle size. These conditions are addressed in the EPA methods for measuring total particulate emissions (Methods 5 and 17) by specifying sampling periods which take into account process cycles, traversing techniques rather than single point sampling, and adjustments in sample flow rate (i.e., nozzle velocity) to match local stream velocity at each point of the traverse so that isokinetic sampling is maintained.

However, a size-specific method, such as one for measuring particulate matter of aerodynamic diameter ≤10 µm (PM_{10}), must combine the considerations of obtaining a representative sample with the need to segregate the sample into two or more size fractions. Inertial sizing devices such as cascade impactors and sampling cyclones must be operated at a constant flow rate to maintain constant size cuts. For a fixed nozzle size, this precludes any adjustment in nozzle velocity to maintain isokinetic sampling. Without the use of new sampling hardware, a PM_{10} sampling method must then become a compromise between the conflicting requirements of inertial particle sizing and representative sampling.

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This manual presents a method, Constant Sampling Rate (CSR), which allows determination of PM_{10} emissions from stationary sources with hardware similar to that used for Methods 5 or 17. The operating principle of the method is to extract a multipoint sample so that errors due to spatial variation of particle size and anisokinetic sampling are kept within predetermined limits. Current specifications were designed to limit error due to spatial variations to 10% The maximum allowable error due to anisokinetic sampling is ±20%; in essentially all sampling situations, cancellation of sampling error will limit overall anisokinetic sampling error to much less than this value.

Operating Principles

In developing the CSR strategy, several specific objectives shaped the details of the method. First, the technique was designed to minimize changes in equipment from that used for Methods 5 or 17. Second, the details of the traversing strategy were selected to limit errors from spatial variation and anisokinetic sampling to the level of more intrinsic errors (such as fluctuations in source emissions or basic measurement inaccuracy). Finally, measurements would be made to provide an average representative of emission rates rather than concentration.

To obtain a sample which is unbiased with respect to particle size, one must sample isokinetically. That is, the gas velocity of the sample stream entering the sampling nozzle must match the local gas velocity in the duct from which the sample is being withdrawn. If the gas velocity in the nozzle is greater than the local duct velocity, the flux of large particles through the nozzle cross-section will be less than that for the free stream; large particles are those which do not follow flow streamlines because of their inertia. As a result, the collected mass of large particles will be selectively depleted. Conversely, if the gas velocity in the nozzle is lower than the local duct velocity, the flux of large particles though the nozzle cross-section will be greater than that of the free stream. The collected mass of large particles in this instance will be selectively enriched. The resulting concentration of very small particles in the sample remains unchanged from that in the duct in either case. The resulting concentration of very large particles in the sample approaches the ratio of the duct velocity to the nozzle velocity.

For any given particle diameter, the anisokinetic sampling error may be expressed as the aspiration coefficient, A, which is defined as the ratio of measured concentration to actual concentration, in terms of the particle Stokes number, K, and the ratio of stream velocity, v, to nozzle velocity, u.

$$A = 1 + (R - 1)\frac{B}{(B + 1)}$$

where R = velocity ratio v/u
B = $(2 + 0.617/R)K$
K = particle Stokes number with respect to the nozzle, $\tau v/d$
τ = particle relaxation time $CD^2/18\mu$, seconds
C = Cunningham slip factor
D = particle aerodynamic diameter
μ = gas viscosity, poise
d = nozzle diameter

The equation shows that, for given stack conditions and particle size, limiting the anisokinetic sampling error becomes a question of limiting the velocity ratio, R. In other words, for a given limit on error due to anisokinetic sampling, maximum and minimum values of R (R_{max} and R_{min}) will yield results within the stated limits. It may also be noted from the equation that B is proportional to particle diameter squared. This indicates that anisokinetic sampling error decreases with decreasing particle size. In other words, when sampling for PM_{10} emissions, the velocity ratio, R, could be outside the 0.9 to 1.1 range specified for total emissions in Methods 5 and 17 and still retain equivalent accuracy.

The choice of the limits on anisokinetic sampling error for CSR is important. An overly generous range could produce data with an excessive amount of error. At the other extreme, small limits would restrict the velocity ratio to the point that most sites would require multiple nozzle sizes for a complete traverse, which would increase the on-site sampling effort. For the purposes of PM_{10}, limits of ±20% on error due to anisokinetic sampling were chosen to specify the limits on the velocity ratios, R_{min} an R_{max}. Actual sampling error for mo sources will be less than the ±20% lim for two reasons. First, point-by-poi R values will usually be something les than the limits, R_{min} and R_{max}, an cancellation of errors will occur becaus R-1 values will be negative at som points and positive at others. Secon the limit of ±20% was determined b assuming a monodisperse sample o 10-μm particles. In actuality, the PM_1 sample is composed of particles wit aerodynamic diameters less than 10 μm.

The goal of a traversing strateg should be to reduce error due to spati variation so that it is not the domina source of error but is comparable to o less than other sources of error. In general, the PM_{10} fraction is expected to b less stratified than total particulate emissions. The lower inertia of the PM_1 fraction would cause less deviation fro gas flow in bends and faster dampin from turbulent diffusion once stratificatio is produced. On the basis of availabl PM_{10} profiles, using 8 to 12 travers points is expected to reduce this type o error to less than ±10%.

Sampling Hardware

As stated previously, one of th objectives during the development of th CSR technique was to make use o existing sampling equipment. Therefore the hardware changes required t operate a CSR sampling system hav been kept to a minimum. Like a standar total particulate sampling train, a CS system may be operated with an out-of-stack filter (analogous to Method 5 or an in-stack filter (analogous to Method 17).

The primary difference between CS and Methods 5 or 17 hardware is th PM_{10} sampling device. Although a number of particle sizing devices may be considered for use as a PM_{10} device, practical considerations eliminate several of the choices. For the purposes of this method, the only single-stage device which should be considered is an in-stack cyclone. Although a single stage of a cascade impactor may provide the appropriate size segregation, problems such as particle bounce and re-entrainment keep this from being an acceptable choice. The multistage device recommended for use with this method is a cascade impactor. Although a series cyclone such as the SRI/EPA five-stage series cyclone provides particle sizing similar to that of a cascade impactor, the mass loading necessary for adequate sample retrieval would require unacceptably long run times for most outlet concentrations.

Before any particle sizing device is used as a PM_{10} sampler, it must be shown to meet some specific performance requirements. These requirements are designed to ensure that the relationship between collection efficiency, particle diameter, and operating conditions is well defined and that the performance of the sampling device is not disturbed by the sampling nozzles used in practice.

One sampling device known to meet the performance specifications is the commercially available version of Cyclone I, the first stage of the SRI/EPA five-stage series cyclone. The outer dimensions and physical appearance of the cyclone may vary, depending on the specific commercial source. The critical inner dimensions, however, are standardized to the original design parameters. Laboratory calibrations have shown Cyclone I produces a 10-µm D_{50} at a flow rate of approximately 0.5 dscfm; the precise flow rate will depend on local stack conditions.

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The complete report, entitled "Application Guide for Source PM_{10} Measurement with Constant Sampling Rate," (Order No. PB 89-193 320/AS; Cost: $15.95, subject to change) will be available only from:

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