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Project Summary

Wide Range Aerosol Classifier

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The purpose of this project was to design, construct, calibrate, and field test a mobile ambient particulate matter sampler (Wide Range Aerosol Classifier) to collect size-classified samples of large aerosol particles. The sampler design was based on a similar stationary sampling system previously constructed by the Principal Investigator, Dr. Dale Lundgren.

The sampler is fitted into a trailer and consists of a large, high flow rate inlet from which five isokinetic samples are withdrawn. Four of the samples are passed through single-stage impactors with different cutpoints and the fifth is passed through a total particulate matter filter. The four impactors were designed to collect particles greater than 7.5 mm, 15 mm, 30 mm and 60 mm diameter. Aerosol particles smaller than 7.5 μm are sized by using separate lower flow rate cascade impactors following the last single stage impactor.

An accompanying analysis lab was set up in a mobile van. Analysis equipment includes an analytical balance and a sample equilibration chamber.

The mobile sampler was briefly field tested in Gainesville, Florida.

The full report was submitted by the Department of Environmental Engineering, University of Florida, in fulfillment of U.S. Environmental Protection Agency grant number R-806714-010. The report covers the total project period from October 1, 1979 to November 30, 1980.

This Project Summary was developed by EPA's Environmental Monitoring Systems 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

The present air quality standard for particulate matter is based upon the total amount of suspended particulate matter collected by the reference method, a high volume air sampler. This sampler has been assumed to collect particles less than ~100 μm diameter (Stokes equivalent) Tests conducted by Wedding and co-workers indicate, however, that the sampling efficiency of the high volume air sampler may be as low as 7 percent for 50 μm particles and 18 percent for 30 μm particles in moderate winds The high volume air sampler is also sensitive to orientation, showing a 20 percent drop in collection efficiency for particles 15 μm in diameter and larger with a 45° shift in wind direction. Because the mass of a particle increases as the cube of its diameters, the mass concentrations measured by the high volume air sampler can also vary widely.

The U.S. Environmental Protection Agency (EPA) in 1979 defined Inhalable Particles (IP) as particles less than 15 μm in diameter and is currently considering an upper size limit of 10 μm. The EPA has also considered establishing a fine particle standard consisting of particles less than ~2 to 3 μm diameter. Consideration of an IP standard has generated considerable interest in defining the total atmospheric particle size distribution. Only then will it be possible to determine what fraction of the total atmospheric aerosol is being collected and what fraction would be desirable to collect by existing or proposed sampling devices for inhalable or other particulate measurements

Lundgren and Paulus[1] previously described a stationary sampling system which effectively sampled large atmospheric particles (up to ~100 μm), and determined the large particle size distribution and total atmospheric mass concentration; they compared results with collections by dust fall plates and with a standard high volume air sampler. That study provided the background for the present project to design, construct, and field test a mobile large particle sampler which determines the mass distribution of large atmospheric particles. With this sampler it is possible to characterize the total particle mass size distribution of ambient aerosol and to compare the results with particle mass data collected simultaneously by the Total Suspended Particulate (TSP) Hi-Vol, the Size Selective Inlet Hi-Vol (SSI), small particle cascade impactors, and the dichotomous samplers. The sampling system will be especially useful for evaluating areas with high fugitive particle concentration. Data showing the relationship between TSP, IP, FP and other measures of Particle Concentration can be obtained while the total atmospheric particle mass distribution is being measured. Differences in the quantity of particulate mass measured by various devices can then be rationally explained and properly related to the aerosol size distribution in the atmosphere.

The objective of this project was to design and construct a mobile particle sampler capable of collecting size-separated mass samples providing mass distribution of the total atmospheric particle size range up to 200 μm aerodynamic diameter.

Procedure

The sampler is fitted into a trailer and consists of a large, high flow rate (1380 CFM) inlet from which five isokinetic samples are withdrawn. Four of the samples are passed through single-stage impactors with different cutpoints and the fifth is passed through a total particulate matter filter. The four impactors are designed to collect particles greater than 7.5 mm, 15 mm, 30 mm, and 60 mm diameter, respectively. Smaller aerosol particles are sized by attaching cascade impactors following the single-stage impactors.

An accompanying analysis lab is set up in a mobile van. Analysis equipment includes a precision balance, optical sizing microscope, and a sample equilibration chamber.

Results and Discussion

Inlet Design.

The major task in measuring large atmospheric particles is transporting a true or representative sample of the particles into a measurement device. This difficulty is particularly serious for the collection of particles larger than ~30 μm diameter because of their great inertia and high settling rate.

Particle settling velocity (Vs) is determined by a balance between the force of gravity acting on a particle and the fluid drag force exerted by the medium through which the particle falls. Simply put, settling velocity increases rapidly with increasing particle size. Sampling tube inlets which are pointed upward will capture a greater porportion of large particles than are in the actual distribution due to the settling of large particles into the inlet. The increase in the relative number of large particles sampled is equal to 1 + [Vs/Vo], where Vo equals the sampling tube inlet velocity. The error can be kept reasonably small if the inlet velocity (Vo) is made several times greater than the settling velocity (Vs) of the largest particle desired. Therefore, a Vo of 25 times Vs would give a permissible error of only 4 percent overestimation for a tube pointed upward. The Wide Range Aerosol Classifier meets this criterion for a 55 μm diameter particle, and an 11 percent overestimation of a 100-μm diameter particle is predicted.

Particle inertia is a function of particle mass. From Newton's first law, where force equals mass times acceleration, a larger force is required to accelerate (or decelerate) a larger (heavier) particle as quickly as a smaller (lighter) particle. Because the size of a particle also effects the drag it experiences from the air, the relaxation time (τ) is used as an indication of its ability to accelerate or decelerate. Particle relaxation time (τ) has been defined as: $\tau = Dp^2p/18\eta$, where Dp is the diameter of the particles, ρ is its density, η is the viscosity of air, and τ has units of time.

It is also convenient to define particle stopping distance l, as the distance a particle will travel when decelerated in a fluid medium (air) from an initial velocity (V) to rest. It has been shown that $l = V\tau$.

Davies[2] uses l to evaluate the effect of particle inertia on sampling efficiency for two situations. When sampling at a known inlet flow rate, *Q*, a suction velocity (Vx) will be produced; Vx is a function of the distance from the inlet orifice To examine the case where Vx is evaluated at a distance l from the center of the orifice, Davies uses the equation $Vx = Q/4\pi l^2$, where Q is the flow rate of the sampler inlet and $4\pi l^2$ is the surface area of a sphere of radius l

More appropriate might be an equation determined by Dalle Valle[3] from measured velocity contours of exhaust hoods For a point at a distance l along the center line from the hood face, $Vx = Q/10l^2+A$, where A equals the inlet face area Davies reasons that if the radius of the inlet (R) is several times larger than l, the effects of inertia will be negligible.

Davies also examined the situation of sampling in a crosswind with some velocity (Vs) and reasons that the inlet radius (R) should be much greater than the stopping distance associated with the wind (i.e., $l = Vw\ \tau$). He suggests that R should be at least 5l. For the mobile sampler, the condition that $R = 5l$ requires that l be less than 6 cm. At a distance of 6 cm from the inlet orifice, the maximum velocity using the latter equation would be 2 m/s (~ 4.5 mph). The stopping distance for a 100-μm diameter particle at this velocity is 6 15 cm. This nearly meets Davies' criteria and suggests that the mobile sampler inlet is dimensionally adequate to efficiently sample 100 μm diameter particles in winds up to ~2 m/s (4.5 mph).

Several researchers have noted that Davies' theoretical criteria seem overly restrictive for efficient sampling and are not met by several commercially available sampling instruments. A theoretical study of sampling efficiencies by Agarwal and Liu[4] took into account both particle inertia and settling. They determined the flow field around a vertical thin-walled inlet from the Navier-Stokes equations and then calculated particle trajectories. They determined a critical particle trajectory which is a distance, Rc, from the inlet axis, such that those particles inside this radius enter the inlet. Sampling efficiency was calculated by comparing the concentration of particles entering the inlet versus the actual concentration of the air sampled.

Agarwal and Liu noted that the sampling efficiency was a function independently of both the Stokes number ($STK = \rho CDp^2Vo/9\eta D$) and the relative settling velocity ($Vs' = Vs/Vo$). The characteristic length and velocity are the inlet diameters, D, and the inlet velocity, Vo. Their research indicates that if the product (STK) (Vs') is less than 0.10, then sampling efficiency will be greater than 90 percent. Agarwal and Liu caution, however, that their criterion for efficiency regards all particles which enter the inlet as sampled, whether or not they impact and possibly stick on the inside wall of the inlet. The value of (STK) (Vs') for sampling 100 µm particles with the mobile sampler is 0.025. Solving for particle diameter with (Stk) (Vs') equal to 0.10 indicates that the mobile sampler can sample particles as large as 130 µm diameter with an accuracy of 90 percent These values assume, however, that Stokes law holds for particles this size

The shroud of the Wide Range Aerosol Classifier was designed to provide a calm air space around the inlet orifice so that the sampler would be less sensitive to cross winds. To be effective, it was made large enough so that particles would not impact on it but would flow around and over the shroud To insure this, it was designed large in comparison to *l*. Using the same ratio of 1:5, this criterion was met for a particle with a stopping distance less than or equal to 1/5 the diameter of the shroud, or 30 cm. This condition was met for 100-µm diameter particle in a 9 m/s (20 mph) wind.

A rain shield designed for use when the sampler is operating consists of a 90-cm flat disk supported 30 cm above the top of the shroud and centered above the inlet. The shield prevents rain from falling directly into the inlet under light wind conditions. A wind driven rain should fall at an angle and impact on the side of the tube From there it should run down the side and into the air plenum box and not into the samplers

Selective Sampler Design

The size-selective sampler inlets were designed to extract an isokinetic sample from the air flowing through the inlet tube. The samplers were constructed of 0.10 cm aluminum. The sampler inlets are of equal area so that an equal volume of air is sampled through each sampler. Each impactor inlet measures 17.8 cm × 6.55 cm. The inlet area was determined by the slot width required for the first impactor; therefore, the Number 1 impactor is a straight nozzle (neither converging nor diverging).

To minimize losses and facilitate construction, a rectangular jet design was used. The impactors were designed with the jets 17.8 cm long in order to leave more room for the airflow over the impactor plate to turn down into the filter. This reduces the particle losses on the walls of the impactor.

The fifth sampler, which collects a total particle sample, was designed with a square inlet so that it would fit better between the impactor inlets. The sides of all sampler inlets are straight to reduce any loss of particles onto the walls. Inlet area of the fifth sampler is the same as for the other samplers.

An additional advantage of using high volume air sampler blowers is that flow controllers are readily available on the market. These flow controllers insure a constant flow rate through the sample so that the total air volume for the sampling period is known and that a representative sample is drawn for each hour over the normal 24-hr period. Therefore, if the total sampling time is known and the flow rate is known and constant, the total air volume sampled is known Aerosol mass concentrations can then be computed. A constant flow rate is additionally critical for impactors because the aerosol impaction efficiency is a function of the flow rate. Field sampling and evaluation at selected sites has shown that the sampler can provide reliable information on the size distribution of particle mass including particles up to 100 µm aerodynamic diameter. The system is self sufficient with the accompanying mobile laboratory for processing and analyzing the collected samples.

Conclusions and Recommendations

The results of limited field testing indicate that the Wide Range Aerosol Classifier (WRAC) can be easily set up at a suitable field location and operated to collect valid 24-hr samples of size-separated atmospheric aerosols. The accompanying analysis van can be used to prepare, condition, and weigh the collected aerosol samples. The samples can be used to determine an aerodynamic particle size distribution based upon the mass of the ambient aerosol.

Calibration tests indicate that the classification is adequate to provide a good characterization of the atmospheric aerosol.

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The complete report, entitled "Wide Range Aerosol Classifier," (Order No. PB 82-256 264; Cost: $9.00, subject to change) will be available only from:

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