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Project Summary

Sampling and Data Handling Methods for Inhalable Particulate Sampling

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The report reviews objectives of a research program established by the EPA on sampling and measurement of particles in the inhalable particulate (IP) size range in industrial process emissions, and discusses methods and equipment that will be required. It summarizes research at Southern Research Institute to support the development of techniques for measuring and characterizing emissions in the IP size range. Topics studied include computer techniques for analyzing cascade impactor data to recover information on IP emissions available from existing data; concepts for maintaining isokinetic sampling conditions at constant flowrates in particle-sizing devices; the design and use of cascade impactors, cyclones, and elutriators as particle collectors for IP sampling systems; and a stack sampling system in which the sampled gas is diluted under conditions simulating those in stack plumes.

This Project Summary was developed by EPA's Industrial Environmental Research 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 U.S. EPA is considering air pollution standards for emission of inhalable particulate (IP) matter from stationary sources. IP matter is defined in terms of particle size, since the extent of penetration of inhaled particles into the lungs depends on their size.

Adequate characterization of a pollution source requires measurement of stack or fugitive emissions from the source and background levels in the ambient atmosphere as well. The concentration and particle-size distribution of the suspended particulate matter and, in some instances, its chemical composition and biological properties must be determined.

In December 1978 a workshop was held at Research Triangle Park, NC, to discuss the IP sampling and analysis problem and the EPA research program on the subject. The workshop was attended by consultants and other investigators experienced in aerosol sampling and characterization.

The consensus of those attending the workshop was that no methods in use were adequate for measuring the amount of material in the IP size range in process emissions. Thus they recognized the need for information on methods that could yield such data or that could be adapted to yield it, and for the research necessary in the development of instruments and procedures for that purpose.

This report contains recommendations resulting from that workshop and summarizes related research at Southern Research Institute on the problem, under contract with the EPA.

Recommendations for the EPA Research Program

The workshop participants recognized that the greatest problem to be faced in developing adequate measurement methods would be the lack of time available. They concluded that 3 to 5 years would likely be required before reliable methods would be available for obtaining the detailed data needed. They also concluded that the only practical course would be the use of available survey techniques to obtain less comprehensive data as soon as possible while research programs were initiated to develop more accurate methods for future use.

Specific needs and problems recognized at the workshop included the fact that, in sampling ambient atmospheres and fugitive emissions, inlets were needed for the available samplers to equip them for measuring mass concentrations in the IP size range.

The lack of realistic and rational strategies for sampling fugitive emissions was also seen as a serious problem.

In sampling stack emissions, the lack of cyclones and inertial impactors calibrated for recovery of the IP size range was noted. It was also recognized that dilution and cooling sampling systems were needed that could simulate the behavior of stack plumes, especially the behavior of condensable vapors.

Advanced techniques for extrapolation of particle-size distribution curves to larger particle sizes to yield additional information on the IP size range were noted as conceptually feasible but not yet in use.

Recommendations

It was recommended that the EPA adopt a standard mathematical performance curve with specified tolerances for sampling devices used to collect and measure IP matter. Figure 1 is the curve which was actually adopted. Any newly developed device would have to be calibrated and shown to agree with the curve, within the tolerances specified. The shaded area was constructed by plotting two log-normal curves through the (13 μm, 50 percent) and (17 μm, 50 percent) points with geometric standard deviations (σ_g)of 1.0 and 1.7, respectively, and allowing 10 percent for wall losses of small particles and 10 percent for penetration of large particles.

Other tasks recommended for prompt action were:

- Analysis of existing particulate emission data, using the Southern Research Institute curve-fitting procedure and the University of Minnesota modal analysis.
- Calibration of inlets for the hi-vol and dichotomous samplers. This would also include the development of a total mass sampler (lo-vol) with the same flowrate and inlet as the dichotomous sampler for use in ambient measurements comparing total mass samplers with the dichotomous sampler.
- A modified EPA Method 5 sampling train was suggested that would include in-stack cyclones with suitable cut points (D_{50} values) for covering the IP size range.

Research at Southern Research Institute on the IP Problem

Analysis of Cascade Impactor Data

Because of the lack of information on the concentration of IP matter at particle sizes larger than about 10μm (the upper limit of the particle-size range covered by an impactor, i.e., the first-stage cut point or D_{50}), a computer technique of extrapolation of the impactor data to 15 μm has been developed. The full report discusses improvements in accuracy of the extrapolation obtained by using a first-order osculating polynomial for fitting the cumulative mass curve between the first stage D_{50} value and an assumed maximum particle size.

The function is a third-degree polynomial which uses the known characteristics of the cumulative mass curve for its solution over the range of particle sizes. Tests of the technique on a number of theoretical unimodal and bimodal size distributions demonstrated a high degree of accuracy in recovering the true cumulative particle concentration. Figure 2 shows an example of the extrapolation technique applied to actual data in which the measured distribution may have been distorted by losses in a buttonhook nozzle or by an improperly calibrated cyclone. It is possible to suppress the fit through upper stages to compensate for these errors. From such studies, it was concluded that the technique could be used for recovering IP concentrations from existing impactor data within a

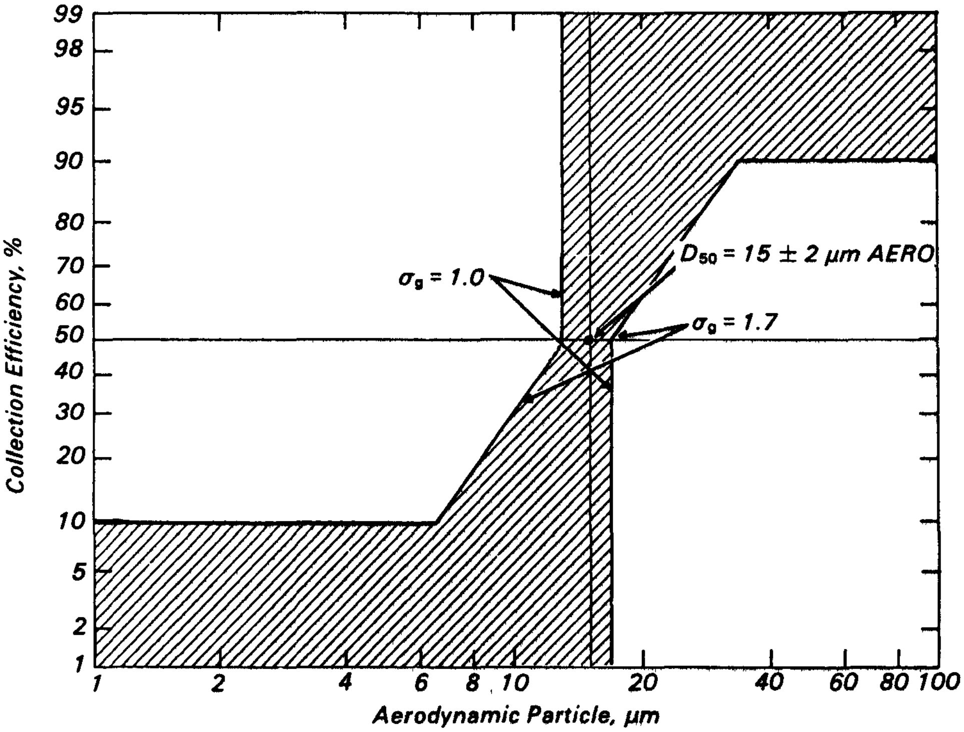

Figure 1. ***Recommended specifications for collection efficiency of samplers of inhalable particulate matter.***

factor of about three, even when no information was available on the type of nozzle or precollector that was used. If the effects of these devices are known, the errors in the IP data are probably within the experimental error of sampling.

Impactor data were also subjected to a modal analysis in which the data were fitted with multi-component log-normal distributions by a simplex minimization method. Data were extrapolated to 100 µm particle diameter by fitting the portion of the size distribution for which data were available. Results were similar to those obtained with the curve-fitting polynomial procedure. IP concentrations could be estimated within a factor of two or better.

Isokinetic Sampling by Particle-sizing Devices

Isokinetic sampling of a gas stream is necessary if a representative sample of suspended particles, notably those larger than 2 µm in diameter, is to be obtained. This presents the problem of maintaining isokineticity in a sizing device such as a cyclone or an impactor, in which the particle-sizing characteristics are a function of flowrate. Several techniques and devices for solving this problem are suggested in the full report, and their expected advantages and disadvantages are discussed. The items include variable cross-sectional area nozzles, split-stream probes, combinations of these devices, probe shrouds, and hot or cool gas recycle systems.

Variable-area nozzles and split-stream probes require mechanical motion in the stack with control outside, presenting problems in mechanical design. Gas recycle systems avoid some of these problems, and systems in which a portion of the filtered and cooled gas sample is recycled have the advantage of avoiding the use of moving components in the stack and being able to use more conventional components. Figure 3 is a schematic drawing of a sampler using the cool gas recycle concept.

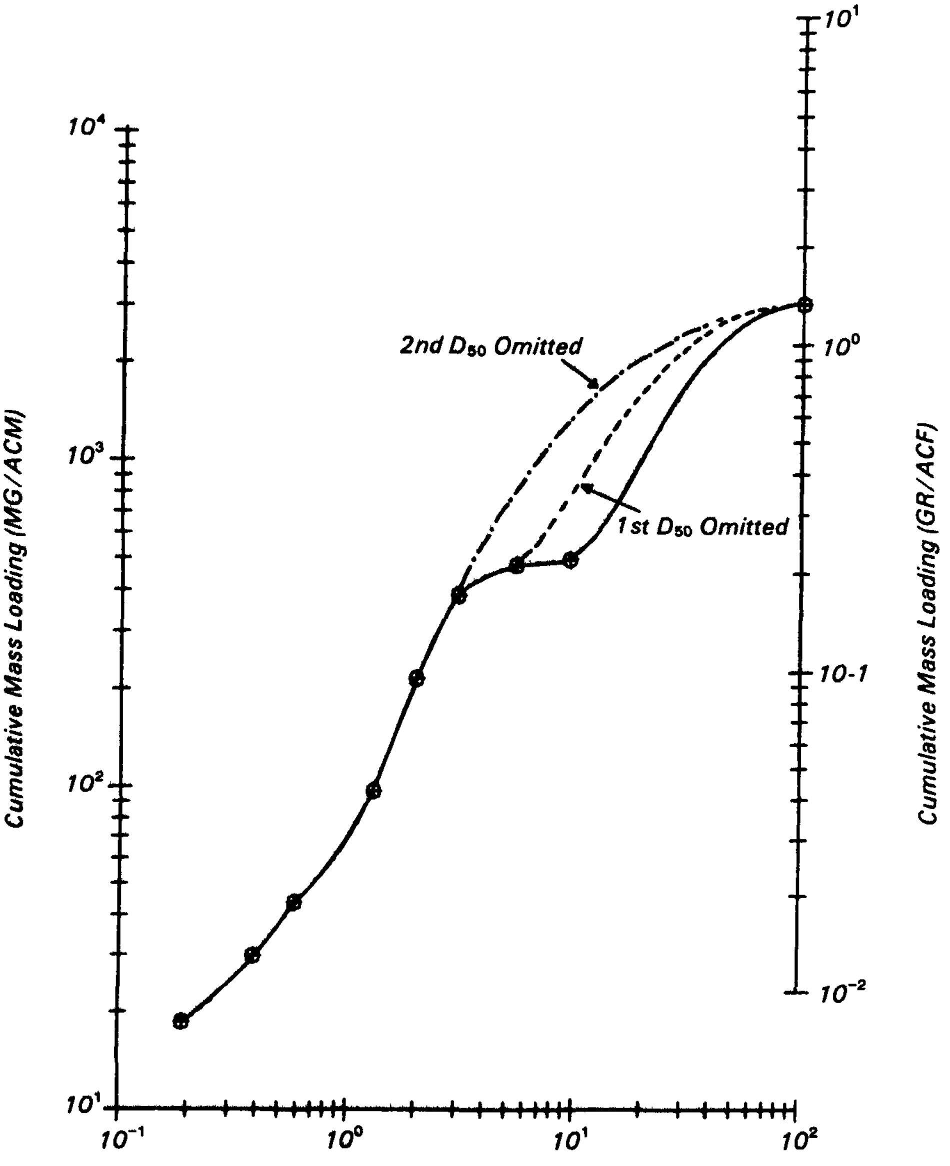

Figure 2. *Cumulative particle-size distribution at inlet to electrostatic precipitator.*

Systems for Sampling for IP Matter

Various particle collection devices were studied in the development of IP sampling systems that would fit EPA specifications. The systems are based on impactors, cyclones, and elutriators as collectors. All of the devices have features that limit their applicability. Impactor stages do not always retain particles efficiently that are much larger than the stage cut point (D_{50} value). The large particles bounce and are reentrained in the gas flow. Virtual impactors can have significant losses of small particles. Cyclones are not subject to those defects but they are bulky and their performance is difficult to predict. Horizontal elutriators are also bulky and their performance is sensitive to orientation. However, re-entrainment is not a problem in elutriators for reasonable gas flowrates, and the theory describing their performance is straightforward and accurate.

Laboratory tests were conducted on several commercially available cascade impactors and nozzles to characterize them for measurements in the IP range of particle sizes. Measurements were made of the collection efficiencies of the impactors for monodisperse aerosols from a vibrating orifice generator.

Collection efficiencies were also measured for horizontal elutriators. The measured values agreed well with values calculated from theory (Figure 4), allowing the preparation of design nomographs for inlet precollectors in sampling systems. Design parameters were calculated for horizontal elutriators to be used with cascade impactors, operated at 14.2 l/min and 149°C, the

EPA Source Assessment Sampling System (SASS), operated at 185 l/min and 204°C, and the EPA Fugitive Ambient Sampling Train (FAST), operated at 5,282 l/min and 23°C.

For the actual field sampling systems for IP measurement, it was decided to develop trains using cyclones for the IP sampling collector. This decision was based on the fact that cyclones are proven field sampling devices without the damaging problems of particle bounce or reentrainment. The only particular design difficulty is the lack of a reliable theory for cyclone performance. Although many attempts have been made to predict the behavior of cyclones from their geometry, or at least to describe their performance by empirical mathematical expressions, it is still necessary to calibrate them experimentally with laboratory-generated aerosols over a range of temperatures and flowrates similar to those likely to be encountered in field use.

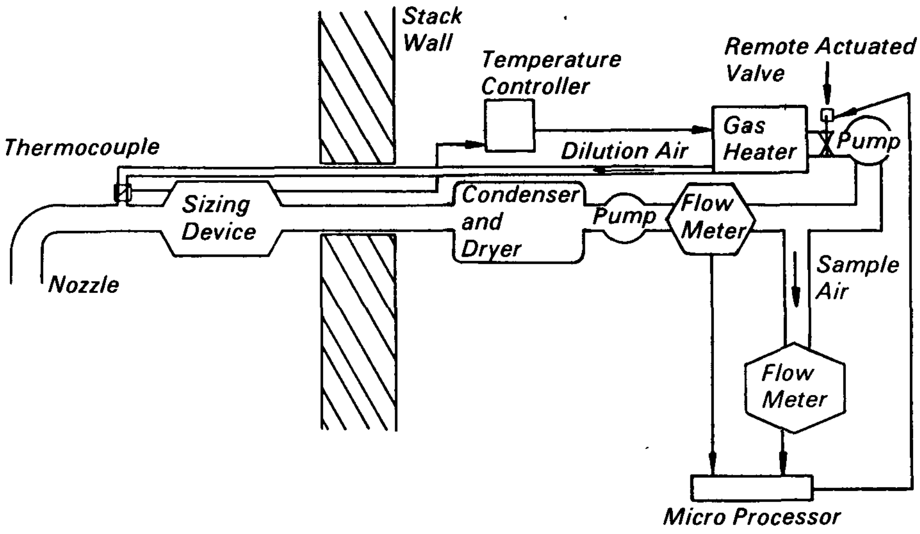

Figure 3. *Cool gas recycle concept.*

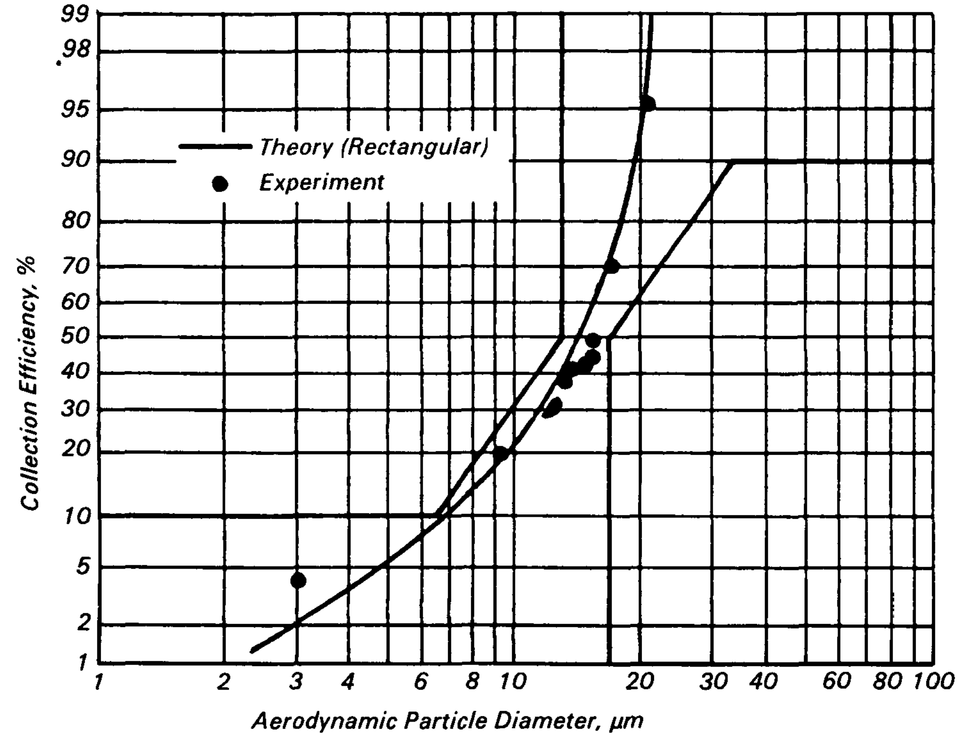

Figure 4. *Theoretical and experimental collection efficiencies for a horizontal elutriator with rectangular cross-section, plate length 38.1 cm, average gas velocity 70 cm/sec.*

Several commercially available cyclones and some especially fabricated were calibrated to provide a basis for design of cyclones for use in an IP sampler. The individual cyclones of the Southern Research Institute's five-stage cyclone system were thus calibrated as part of this empirical design process.

Under laboratory conditions (temperature 22°C, flowrate 28.3 l/min, and particle density 1.0 g/cm^3) the cut points of the individual cyclones are 5.6, 2.1, 1.4, 0.63, and 0.33 μm, as shown by the calibration curve of efficiency vs. aerodynamic particle diameter in Figure 5.

From design parameters developed in the previous cyclone calibration studies, geometries for the IP cyclones were selected. Two cyclone systems were designed, and evaluated: a cyclone to be used as a precollector for cascade impactors, and a system of two cyclones (Figure 6) and a filter in series, to be used as the primary system for measuring IP and fine particle concentrations. Both systems were designed for high-temperature operation in process streams. The precollector for impactors and the first cyclone in the series train had collection efficiency curves satisfying the specifications for IP samplers shown in Figure 1. The second cyclone in the series train was designed to have a D_{50} value of 2.5 ± 0.5 μm aerodynamic at the flowrate required for the 15 μm cut in the first cyclone.

To measure the particulate formed by condensation of volatile material as the hot stack gases mix with ambient air, a Stack Dilution Sampling System (SDSS) was designed. The system was designed to be used with the in-stack IP dual-cyclone sampler. Figure 7 shows major components of the apparatus. In operation, gas from the stream being sampled is drawn through the IP cyclone sampler, in which particles larger than 15 μm and those 2.5-15 μm are removed in two stages. The gas containing the fine particle fraction (less than 2.5 μm) and the condensable vapors passes through the dilution chamber, and through

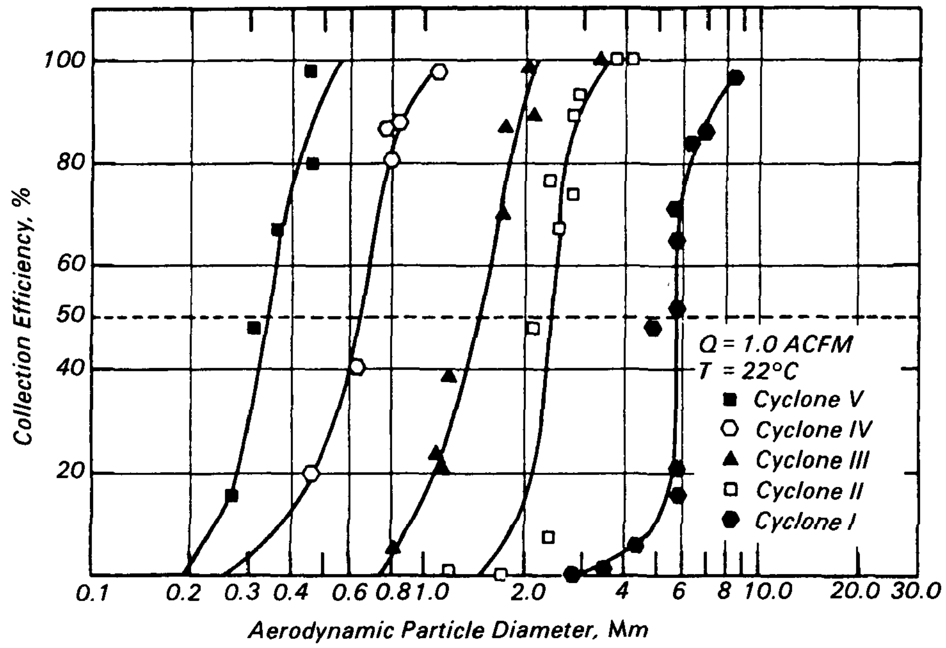

Figure 5. *Calibration curves for the five-stage cyclone system. Flowrate 1.0 ft^3/min, temperature 22°C.*

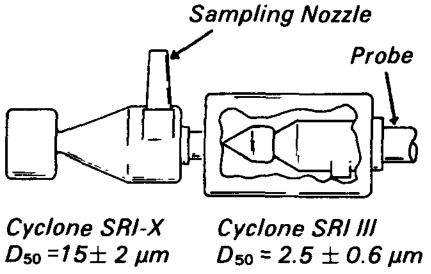

Figure 6. *Sketch of two-cyclone system.*

heated probe and sample line and is introduced axially into the bottom of the cylindrical dilution chamber. Here the gas is mixed with dilution air to form a simulated plume which flows up through the dilution chamber, and through a standard hi-vol filter, which collects the fine particles and any new particles formed by condensation. The design of the dilution chamber simulates the flow patterns and mixing times observed in actual plumes.

A field version of the dilution system was constructed to the following specifications:

Active length of dilution tube, 1.22 m (4 ft)
Total height of sampler, 1.8-2.1 m (6-7 ft)
I.D. of dilution tube, 21.3 cm (8.4 in.)
I.D. of sample inlet tube, 4.27 cm (1.68 in.)
Active dilution volume, 43.6 l (1.54 ft^3)
Sample flowrate, 17 1/min (0.6 ft^3/min), determined by cyclone cut point
Dilution flowrate, 425 1/min (15 ft^3/min)
Dilution factor, 25
Residence time, 6.2 sec Sample velocity, 25 cm/sec at 150°C Dilution air velocity, 19.8 cm/sec at 21°C

The system was tested on flue gas from a domestic furnace burning fuel oil under controlled combustion conditions. The results indicated that organic chemical vapors condensed to solid particles within the dilution chamber as expected, at dilution ratios of 10 to 40. Higher dilution ratios favored a larger number of small particles.

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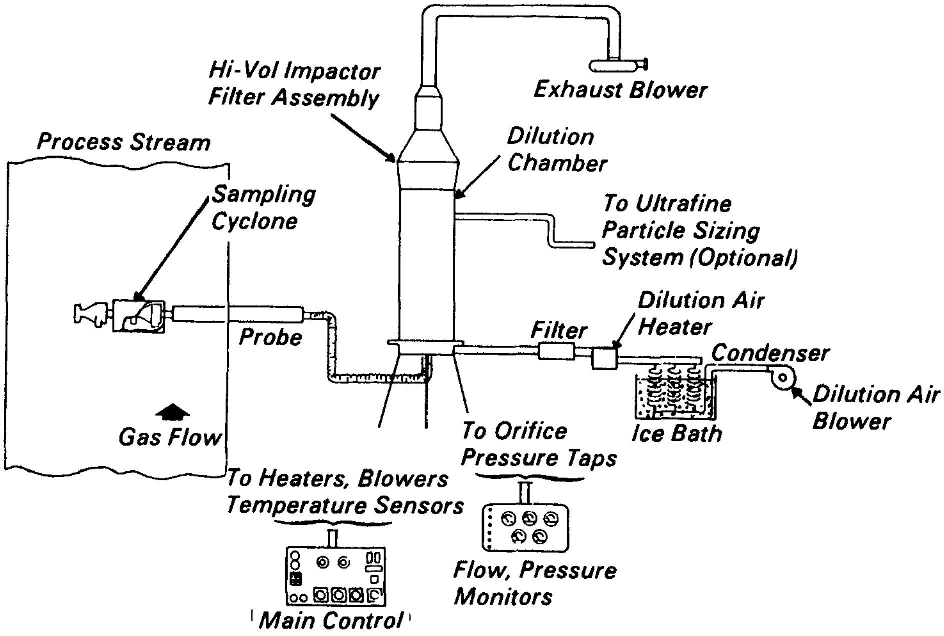

Figure 7. Diagram of stack dilution sampling system (SDSS).

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The complete report, entitled "Sampling and Data Handling Methods for Inhalable Particulate Sampling," (Order No. PB 82-249 897; Cost: $22.50, subject to change) will be available only from:

National Technical Information Service
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