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Project Summary

In Situ Field Portable Fine Particle Measuring Device

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An *in situ* fine particle measuring device--the Fine Particle Stack Spectrometer System (FPSSS) has been developed. It is a laser-fed optical system with detection by near-forward light scattering. Sample volume is established by a high-resolution optical system viewing particle images in a dark field through a masked beam splitter. The FPSSS covers an 0.5 to 11.0 µm size range with 60-channel resolution. Absolute theoretical accuracy is +20% of size for completely unknown refractive index. The instrument is designed to operate continuously at in-stack temperatures up to 250°C at flow velocities up to 30 m/sec. It has been laboratory characterized and field tested on coal-fired power plants at both the inlets and outlets of control devices. Its performance indicates good agreement with impactors and excellent agreement with opacity meters in computed mass loading and optical opacity. Its size resolution is greater than other currently known techniques. Its eventual use will be directed at characterizing particulate emissions of stacks or other stationary sources and qualitatively evaluating the performance and collection efficiencies of particulate control devices now in operation.

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 development of the *in situ* Fine Particle Stack Spectrometer System (FPSSS) was intended to characterize the particulate emissions of stacks and other stationary sources and to qualitatively evaluate the performance and collection efficiencies of particulate control devices now in use or under development. The primary EPA design criteria that the FPSSS had to satisfy were to provide *in situ* high-resolution particle sizing over a size range from 0.5 to 5.0 µm diameter, with number densities in this range above 10^4 cm^{-3} and integrated particulate loading from 0.3 to 3.0 g^{-3}. The FPSSS was also required to operate at temperatures from 20 to 250°C and at flow velocities from 1 to 30 m sec^{-1}. The full report describes the design, development, and testing of this new high-resolution in-stack particle size spectrometer system.

Approach

Probably the greatest desire of research in performing particle size measurements is to do so without disturbing the particles; i.e., making the measurements *in situ*. In some respects the concept of *in situ* sampling is unattainable; one desires to minimize sample perturbation. As far as single particle sizing devices are concerned, this ability to size particles *in situ* generally requires additional imaging technology to dimension sample volume.

The FPSSS design draws heavily from previous work. In essence, the FPSSS is the result of using existing technology rather than the result of basic research and development. It has a near-forward light-scattering optical system with an expanded 60-channel 0.4 to 11.0 µm size range divided into four subranges of 15 size channels each. The instrument is capable of relatively accurate measurements at number densities up to 5 x 10^4 cm^{-3}, without significant sensitivity to refractive index. An optical velocimeter has been designed and incorporated in the FPSSS. The instrument can operate continuously at 250°C temperatures utilizing a water-cooled head design and external heat exchanger.

Extensive theoretical modeling of thermal and optical performance has been utilized in configuring the FPSSS probe head. Wind tunnel facilities played an extremely important role in measuring aerodynamic impacts of the FPSSS sampling section. Calibration included laboratory and wind tunnel tests on particulates having known or independently verifiable size distributions. Field tests on three operating coal-fired power plants, conducted during the course of this work, are discussed in detail.

Field Tests

Field tests were conducted at the Colorado Public Service Company's Valmont power plant in Boulder, CO, and at Duke Power Company's Riverbend Plant at Charlotte, NC. The Valmont plant was the primary test site, with a variety of short tests during early development as well as final testing with comprehensive comparisons.

Conclusions and Recommendations

From the results of theoretical analysis and laboratory and field testing, the FPSSS is considered to be satisfactory for *in situ* size distribution measurements in a hot stack environment.

There remain a number of unanswered questions that further use of the FPSSS in the field should clarify. For instance, there is the possibility that large particles might be rejected more easily if turbulence indicates significant trajectory deviations from normal flow. Users of the FPSSS in situations where large particles are dominant would be wise to rotate the probe head and determine if any position (other than normal to the flow) maximizes count rate at large sizes and leave it in that position if it does.

The stability of the internal velocimeter is questionable;its accuracy is probably 10-15%. It may well be the limiting factor in the overall accuracy of the basic measurement system. Unlike impactors, which only measure velocity to attempt to provide isokinetic matching but then accurately meter the actual sample flow, the FPSSS is an *in situ* device requiring *in situ* flow measurements as accurate as the final desired result. Again, improvements in the circuitry could alleviate instrumental sources of error, but little can be done if the laser beam width is not stable. The laser beam width is, of course, directly related to the transit time and (thus) velocity computation. Multimode lasers can undergo temporal fluctuations in output beam diameter amounting to at least 10%. Thus, it is probably impossible to achieve better accuracy without additional optical hardware. For instance, a separate detector (photodiode and beam splitter) could be used to measure transit time across a mask. As long as the mask is always smaller than the laser beam, fluctuations in the laser beam diameter would be a factor. Another attractive possibility is to use a laser operating in TEM_{00} mode, a doughnut-shaped beam profile where size is invariant. It is also a smaller beam that could allow for measurements at still higher number densities without changes to the optical system.

Finally, it should be recognized that the FPSSS is new and highly sophisticated, with more opportunities for failure than with conventional techniques. It becomes contaminated with time, requiring cleaning. It is thus viewed primarily as a research or investigative tool and not a routine monitoring device. As is the case for all measurement processes, an experienced operator is the best guarantee of successful use. The real utility of a device like the FPSSS is not in extending sensitivity to the smallest particles or in having the ability to handle the highest number densities. Rather, it provides measurements of sufficient spectral quality to gain insight into processes that produce changes in particle size and number density and it retains reasonable verisimilitude in integrated properties such as mass loading and opacity.

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*The complete report, entitled "*In Situ *Field Portable Fine Particle Measuring Device," (Order No. PB 84-199 793; Cost: $20.50, subject to change) will be available only from:*
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