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Project Summary

Development of a Charged Grid Sensor for Airborne Carbon Fibers

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This development project addresses the sensing and measurement of carbon fibers moving in ventilating ducts or exhaust stacks of incinerators. The sensor system employs a series of five electrically charged grids with different grid spacings for sensing fibers, determining their lengths, and presenting a count of the fibers detected. The system senses carbon fibers shorter than 0.1 mm moving at velocities from 2 to 4 m/s and measures fiber populations of up to 100 fibers/m³ in each of five lengths ranging from 0.1 mm to 1.5 mm. Areas requiring further development are identified, as are design requirements, alternative materials and fabrication techniques for producing a unit to be evaluated in a field test. In a companion development project, a mobile flow test facility was produced for evaluating and calibrating instrumentation to measure fibrous aerosols.

This Project Summary was developed by EPA's Environmental Sciences 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 selection of a measuring system based on electrically charged grids applied a well established technique to the requirements of a continuous monitor instrument for carbon fibers emitted from stationary sources and moving in ducts or stacks. Application of the charged grids to an in-duct monitor instrument required extending their sensing capabilities to include fiber lengths of 0.1 mm or less. The developed system consists of five grids in series, with each grid tailored to sense fibers of a specific length range. Figure 1 illustrates the system concept. In operation, electrical discharges from the grid wires eliminate fibers from the gas stream; the combination of spacing and applied voltage establishes a threshold length for each grid so that all fibers longer than the threshold length are removed from the stream and sensed by a specific grid. The last grid in the system has a threshold length less than 0.1 mm.

Prototype Instrument Charged Grid System

The operating concept for the measuring system is based on experimental measurements of the burnout of carbon fibers between charged electrodes. For fibers contacting the electrodes, burnout is assured at field strengths of 2000 v/cm (2 kv/cm). A field strength of 10 kv/cm precipitates an arc breakdown burnout for fibers of lengths equal to half the distance between the electrodes.

These results led to the concept of five grids in series, with each grid sensing and eliminating fibers of a specific

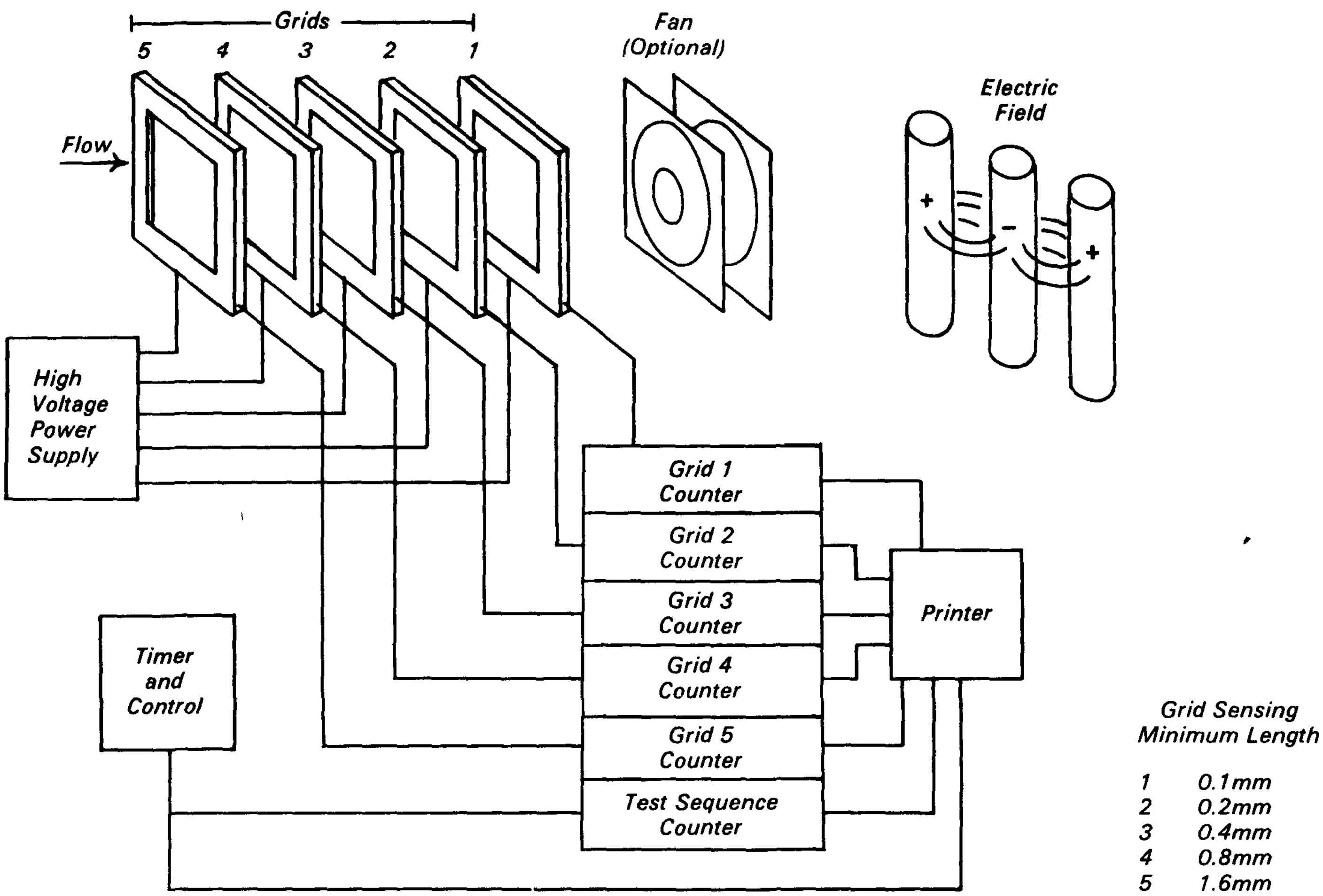

Figure 1. ***Concept schematic diagram for the charged grid sensing and measuring system.***

length range. NASA's experience with fibers emitted from pool fires and with measurement of fibers passing through air filters in ventilating systems showed an upper practical limit for fiber lengths to be in the range of 3 to 4 mm. Data from the processing of carbon fiber composite scrap mixed in refuse-derived fuel further confirmed an upper practical limit of fiber length in the range of 3 to 4 mm. All measurements from fiber releases showed the majority of the population to be less than 1 mm long.

The discharge of a capacitor by shorted grid elements provides a triggering signal to a sensing circuit that feeds a counter. The events at each grid are counted separately; thus, the system determines the length distribution as part of the total count. A timer circuit allows the count at each grid to be related to a population of fibers moving in the air stream. Thus, for any set of flow conditions, the system determines the presence of conductive fibers in the stream together with their length distribution and, over a period of time, determines an average volumetric population of fibers moving in the stream.

Flow Test and Calibration Facility

A mobile flow test facility was designed, built, and made operational for evaluating and calibrating the five-grid sensor system. The facility employs a recirculating low-speed wind tunnel to simulate flow conditions representative of industrial ventilating systems. The fiber-dispensing equipment and conductive fiber measurement equipment developed for NASA was installed as part of this system. The principal features of the facility are shown in Figure 2.

Results of Testing and Evaluation

Evaluation and calibration testing established the system's operating capability and identified areas requiring further development. The testing consisted of bench evaluations, which did not produce quantitative data, and operations in the flow simulation facility, which generated quantitative measurements.

Operational Evaluation Testing

The operational evaluation testing addressed the burnout of fibers at the grids, the abilities of grids to respond to fibers of the length ranges intended by design, and the responses of the system to a flow of fibers. These tests were performed in a flow passage on a bench top or within a small chamber. An exit fan (see Figure 1) established the flow velocities. The principal observations and results from these evaluation tests are included in the following paragraphs.

Burnout of Fibers. A grid discharge that either shortened a fiber or cut it into segments could introduce errors in

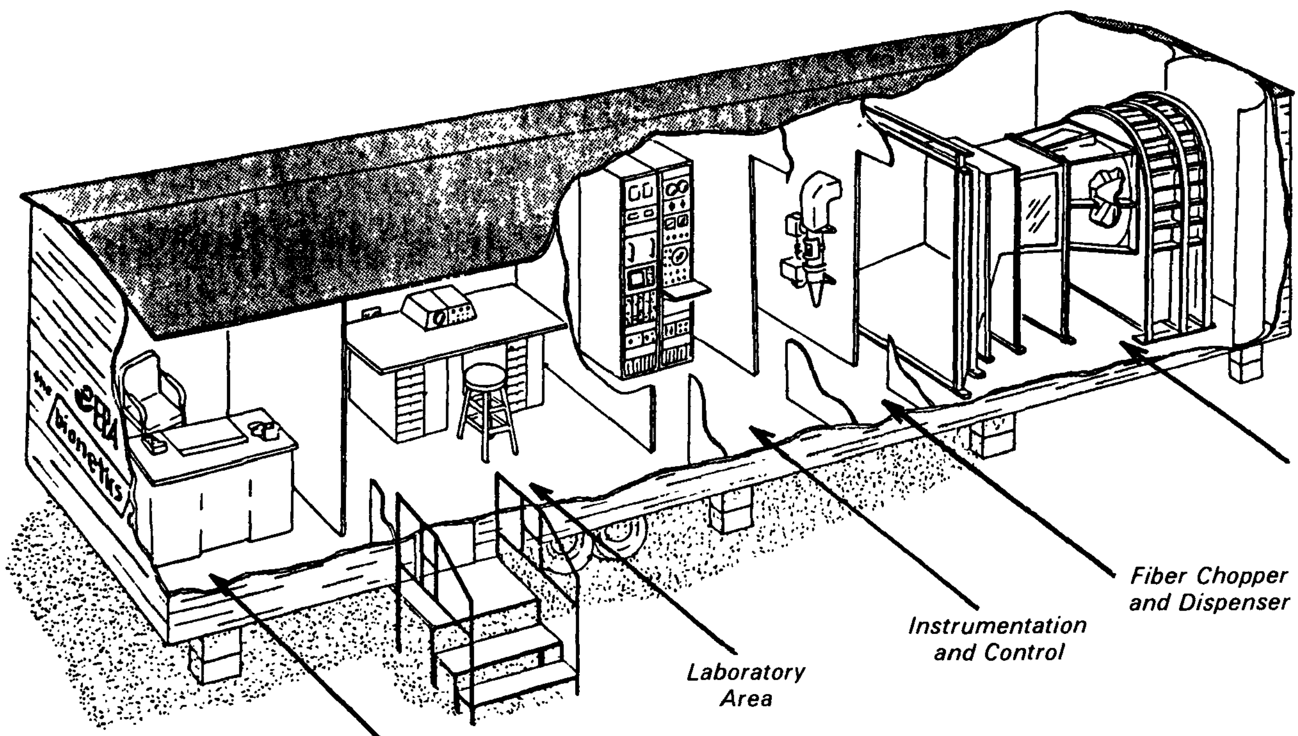

Figure 2. *Mobile flow test facility.*

counting. Such an effect would necessitate statistical correction of the counting results before measuring data could be accepted. That effect did not appear during chamber or fire-release testing; nevertheless, operational verification was considered necessary for the five-grid sensor. For the evaluation, the grids were operated while small quantities of pre-cut fiber were introduced into the fan-induced flow. In this mode, cutting or partial burning of fibers at the front grids (5 and 4 in Figure 1) would be followed by counts at the downstream grids (2 and 1); any fibers less than 0.1 mm long would be collected on a filter downstream of grid 1 (and upstream of the fan). Operation with fibers having lengths greater than 0.8 mm (grid-4 spacing) did not produce any downstream counts (grids 2 and 1) or any fiber residue on the filters, indicating that any fiber that. precipitated a discharge was consumed.

Fiber-Length Discrimination and Sensing. This series of evaluations was performed in a small chamber. Air-flow through the instrument was induced by the exit fan. Single fibers were lofted by means of a pulsed air jet blowing through a clump of fibers cut to lengths of 3 mm (long), 1 mm (medium), and 0.5 mm (short). In qualitative testing, the grids responded according to the length distributions of the cut fibers.

Evaluation and inspection of the grids indicated certain effects which compromised the operation of the five-grid sensor. Fibers adhered to the Teflon* walls of the flow passages between the grids; fibers contacted the grids before the voltage had recovered from the burnout; and there was evidence that, at the higher velocities, fibers passed through the field without making contact or precipitating an arc. The fallout of fibers by adherence to the Teflon is a materials-related effect, indicating that the surface selected as the flow-passage liner requires modification.

Operation in the Flow Test Facility

Continuing operations in the flow test facility evaluated length distributions and sensitivity to population at flow velocities simulating the conditions in ventilating ducts. For this evaluation, a calibration rig was constructed having the same flow areas and flow resistances as the five-grid sensor. The calibration unit was designed to have the same flow velocities at the same power settings as the five-grid sensor, while capturing all fibers on a filter element. The five-grid sensor unit and the calibration unit were installed in the test section so that they were equidistant from the walls and from each other. Velocity measurements around the calibration unit showed it passed 10% of the flow associated with its frontal area; therefore, the filter in the calibration unit provided a means to measure the population of fibers flowing in the tunnel. The evaluation measurements were performed at duct-stream velocities of 1.52, 3.05, and 6.1 m/s, using cut fiber lengths of 0.2, 1.0, and 2.0 mm. All grids operated and provided data which show effects of fallout, saturation, and velocity. Over a portion of the operating regime tested, extraneous effects did not appear significant and, within that portion of

*Teflon is registered trademark of E I. DuPont de Nemours and Co the regime, the system accurately measured the fiber populations.

Conclusions

The three principal objectives of the development effort were met. A prototype five-grid unit was designed, built, and tested. The efforts to configure a system required that alternative manufacturing techniques be evaluated. The system was tested operationally in a flow facility that could simulate the conditions of ventilating ducts or stacks and inject a controlled fiber population into the gas stream. This sensor system is suitable for continuous monitoring. The pertinent supporting results may be summarized as follows:

Prototype Demonstration of Operation

A five-stage electrically charged grid sensor capable of sensing airborne fibers less than 0.1 mm long operates effectively over a range of duct velocities from 2 to 4 m/s. At lower velocities, results are influenced by fallout; higher velocities may not allow sufficient time for a fiber to align with the field and precipitate a discharge. Populations from 10 to 100 fibers/m^3 can be collected within the length range sensed by each grid. The present upper limit to the population that can be counted is determined by the sensing rate designed into the electrical operation of the system. At higher populations, the grids can be saturated by multiple contacts, allowing fibers to pass undetected.

Evaluation of Fabrication Techniques

The prototype unit was fabricated from materials compatible with the flow environment at the exit of an incinerator employing an active particulate control system (controlled air-with-after-burning incinerators which could have exhaust temperatures exceeding 540°C were not considered). Type 304 stainless steel was used for the grids, Teflon for the grid supports and inter-electrode insulator, and Sauereisen #8 cement for both the interelectrode insulation and grid retention system. Studies showed that either chromium-nickel or chromium-nickel-iron alloys were required for grid materials. Several ceramics or cements showed properties suitable for structure or insulators. Conventional machining techniques can be used in fabrications; however, nonstandard techniques may be required for joining electrical connections.

Flow Simulation Facility

A recirculating wind tunnel wa designed and built as a mobile sel contained facility for evaluating an calibrating fiber sensing instrumen under conditions simulating the flo velocities associated with ventilatin ducts or exhaust stacks. The un provides flow velocities covering th range that would be encountered i industrial operations. The test section the flow facility has dimensions con parable to actual ducting and allov operation of an instrument under sim lated free-stream conditions. The sy tem for introducing and maintaining fiber population provides repeatab fiber populations. As presently co figured, the flow facility provides velo ities ranging from 0.3 to 11 m/s. For wide range of fibrous aerosols, fib populations of more than 100 per cut meter appear to be within the capabil of the system.

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***William D. Conner** is the EPA Project Officer (see below).*
The complete report, entitled "Development of a Charged Grid Sensor for Airborne Carbon Fibers," (Order No. PB 83-116 848; Cost: $10.00, subject to change) will be available only from:
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