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Project Summary

Development of Instrumentation for Monitoring Carbon Fiber Emission

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This document reports the design of an electrical instrument which utilizes a variable capacitance in one leg of a resistance-capacitance feedback network to provide discriminatory information regarding the air stream particulate material. Sufficient testing was performed on the breadboard to validate system concept. The current instrument counts fiber mass and indicates fiber diameters to yield an approximate count of individual fibers. Its operational range has a lower limit of 10^4 fibers and an upper limit internally restricted for this breadboard stage of 2×10^8 fibers/m^3. The program scope did not allow completion of a prototype design; therefore, emphasis is placed on recommendations to complete design efforts.

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

Previous studies have reached no consensus on the most promising continuous real-time carbon-fiber (CF) monitor for targeted environments such as waste incineration, manufacturing and processing. Therefore, past CF activity and instrument performance were critically reviewed for concept applicability, in light of recent advances in electrical and electronic equipment that significantly increase the capabilities and signal-to-noise ratio (discriminative sensitivity) of instrumentation. It was determined that no one method could meet all desired operational parameters. Because of objections to existing methods, two feasible design options were considered:

a. Take advantage of the most sophisticated electronic data reduction schemes, advanced sampling, and microprocessing capabilities to develop a state-of-the-art sensing device, or

b. Develop a new system to provide the most information possible utilizing the resources presently available.

The first option would involve extensive research and development and material cost, limiting efforts to electrical and instrumentation schemes and thus would yield an untried instrument. In the best judgement of the scientists and engineers involved, such a sophisticated instrument would be expensive, delicate, and require skilled operation, and yet still possess objectionable features. The instrument could prove useful for test facilities or to provide calibration and baseline data, but it would not fulfill the intent of the contract.

Therefore, the second design option was chosen, thereby maximizing effort to provide a practical instrument for its function and operating environment. A secondary objective was to demonstrate that an inexpensive electronic circuit could be developed which could provide the needed information required by a continuous CF monitor.

Following a review of existing CF monitors, a monitor development program based on the concept of a

resistance-capacitance (R-C) feedback network utilizing a variable capacitance in one leg of two stable twin-T oscillators was selected.

Instrument Description

The CF monitoring system is a frequency shift device, whose sensor acts as a variable capacitance in one leg of an R-C feedback network. The frequency at which a 180-degree phase shift takes place across the R-C feedback network is the frequency of oscillation. A reference oscillator provides the second waveform, thus two stable R-C (twin-T) oscillators' waveforms are fed into a detector system which outputs a difference frequency. This difference frequency is fed into a frequency to voltage (F/V) converter which produces a direct continuous voltage output that is proportional to the capacitance variance (the fiber concentration).

The reference oscillator differs from the sampling oscillator which utilizes a unique air dielectric capacitor in its frequency feedback circuit (Figure 1). The sampling unit consists of concentric rings (plates) constructed to allow gaseous flow through it. The conductive impurities in the gaseous flow will produce the above-mentioned phase shift. The reference frequency is provided by an identical oscillator which utilizes a fixed capacitance.

The sensing capacitor was designed so that it may be suspended in an incinerator stack or vent ducting and the remaining circuitry may then be more conveniently situated. This feature decreased size requirements (thus disturbance in airflow, due to the location of the device in the air stream).

Instrument Development and Testing

Two discrete sequences of instrument testing were conducted. Standard development testing paralleled the breadboard development and fabrication tasks and was concluded by a pretest to confirm concept design. The second sequence tested the final breadboard to establish the capabilities and limitations of the instrument.

Figure 2 displays the initial chamber used to test the CF monitor. A known mass of fibers was placed in the chamber, and a simple squirrel cage fan generated fiber movement (chamber turbulence). Knowing the internal volume of the chamber and observing the distribution of the fibers, gross measurements verified previously made circuit performance calculations.

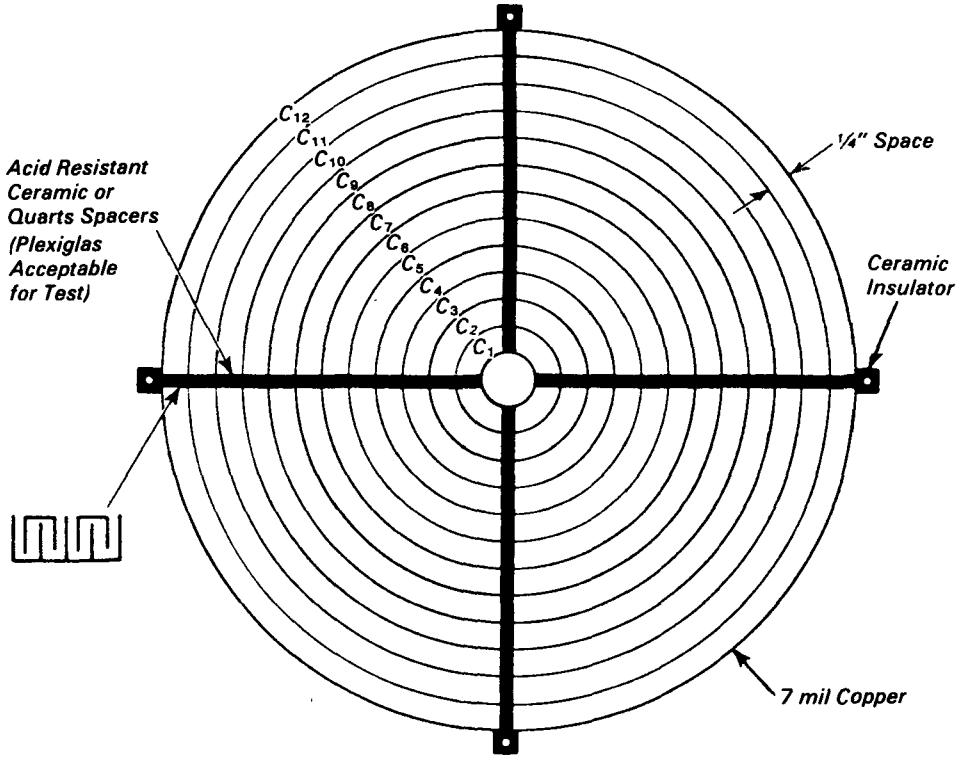

Figure 1. Variable capacitor of carbon-fiber monitor.

The variable capacitor used as the sensor was constructed of 7-mil copper according to the dimensions provided in Figure 1. The spacers were made from Plexiglas because of ease in milling. Alternate concentric circles were electrically connected to provide the plates comprising the capacitor.

Although the initial chamber was modified into a recirculating system, its inability to identify all particle loss and failure to maintain defined CF-exposure concentrations necessitated the system be redesigned as a simple fall-through chamber (Figure 3).

The carbon fibers used to test the sensor were purchased from Union Carbide Corporation and were chopped to specific lengths prior to shipment. When the fibers were received, electrostatic bonds were established causing balls of $< 10^{20}$ fibers. Freeing single fibers was a major problem, because testing depended on the settling of discrete fibers at known concentrations. The well-established CF clumps proved resistant to wetting, and several solvents were tried before the proper mixture and concentrations were discovered. To break up the clumps, fibers were mechanically agitated in the solvent and then dried in an antistatic atmosphere, thus yielding the desired individual fibers.

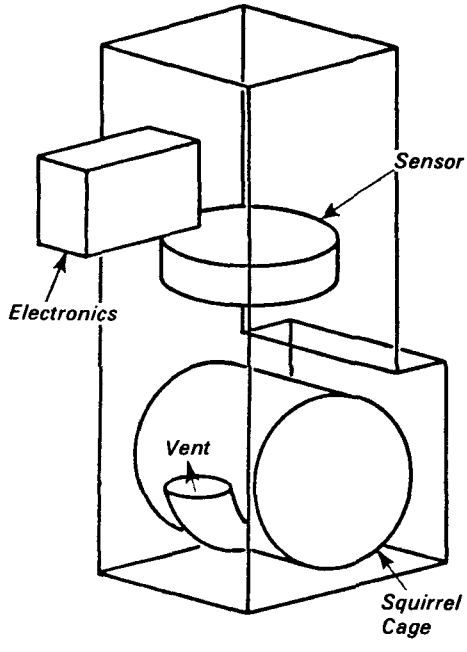

Figure 2. Fan-blown test chamber.

Following the separation treatment of the fibers, controlled quantities were

injected into the test chamber to begin test procedure sequence. The sequence began after establishing the CF loading, initiating the chamber airflow, and making final sensor adjustments. The beginning of CF injection into the airflow began a count of elapsed time. CF injection ended 30 seconds later, airflow was stopped at 45 seconds, and the tests were discontinued when 300 seconds elapsed. Immediately below the sensor was a strip of sticky paper which sampled a known area of the CF cloud while allowing the fiber cloud to pass through the capacitor undisturbed. All fibers passing through the monitor were collected on a glass fiber filter at the bottom of the chamber. A shield around the sensor caught all fibers not passing through the monitor. Counts of collected fibers enabled calculation of the fiber cloud concentration with reasonable accuracy. A gravimetric method was utilized in early runs (corrected by moisture curve analysis performed concurrently with the test), but once fiber counts established the negligible fiber loss only the counts were performed. The result was a uniform distribution with an appropriate settling velocity which permitted accurate CF concentration measurements.

Each test run produced a fiber concentration and distribution according to the output of (a) actual microscopic counts, (b) an electronic count number, (c) strip chart recording, and (d) a DC signal stored by a magnetic tape recorder. The strip chart readings and the fiber count data were principally used to verify instrument performance. Table 1 shows the fiber count data obtained for runs 1 through 5.

Additional test runs were performed with only an airstream or an injected water mist, and with water mist and CF present. No effect was seen by the monitor; it performed normally in each instance.

Results and Conclusions

Results of the instrument response to changing fiber concentrations appear in Figure 4 and show that the changing fiber concentration response is linear for the three lower concentration tests. However, when coupled with the changing fiber resistance effect a double integral effect is seen at high concentrations. This effect was seen moving the high concentration point off scale where electronic limitations inhibit continued response.

Laboratory tests indicate an electronic device which measures the capacitance change resulting from the presence of conductive carbon shunted across the planes of a variable capacitor has potential for further development.

The current breadboard instrument counts fiber mass and indicates fiber diameters to yield an approximate count of individual fibers. Its operational range has a lower limit of 10^4 fibers/m^3 and the

*Table 1. Fiber Distribution and Totals for Test Runs**

Run No.	≤ 1mm	2mm	3mm	4mm	5mm	Total
1	3.6	2.2	1.0	1.6	Negligible	8.4
2	11.6	3.9	2.6	4.4	——	22.4
3	8.9	3.0	1.9	3.7	Negligible	17.5
4	13.6	4.8	4.5	5.5	Negligible	28.4
5	4.6	1.4	1.0	4.2	——	11.2

*Fiber concentration for all lengths = 10^4 fibers/m^2.

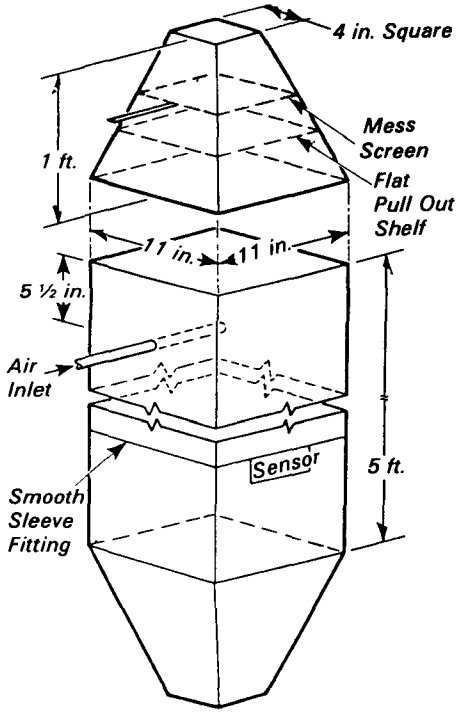

Figure 3. Gravitational settling test chamber

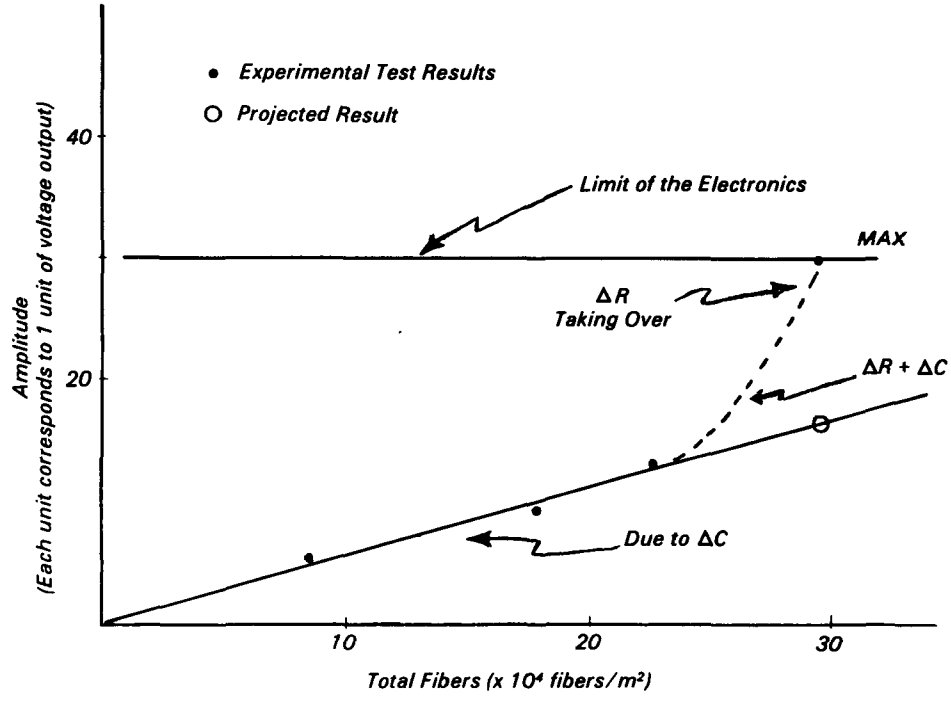

Figure 4. Carbon-fiber monitor output vs. fiber concentration.

upper range is restricted to a maximum of 2×10^8 fibers/m^3 by the internal constraints placed in the system for testing convenience.

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***William D. Conner** is the EPA Project Officer (see below).*
The complete report, entitled "Development of Instrumentation for Monitoring Carbon Fiber Emission," (Order No. PB 83-233 726; Cost: $11.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
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