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AEROSOL PARTICLE CONCENTRATION DETERMINED USING AN ACOUSTIC TRANSDUCER

R.-H. CHEN

Department of Mechanical, Materials and Aerospace Engineering, University of Central Florida, Orlando, FL 32816-2450, *U.S.A.*

AND

T. E. MILLS

Engineering Technology, Inc., 3275 *Progress Drive, Orlando, FL* 32826, *U.S.A. and Department of Mechanical, Materials and Aerospace Engineering, University of Central Florida, Orlando, FL* 32816-2450, *U.S.A.*

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1. INTRODUCTION

Detection of aerosol particles finds important applications in both commercial and military sectors. Commercial and environmental applications include monitoring clean rooms and maintaining particle emission standards. The ability to detect biological warfare agents with 2–10 μm sizes and millimeter-sized wave obscurants at concentrations of the order of a few tens of particles per liter (ppl) is desirable. This study aims to demonstrate a relatively inexpensive tool (the acoustic transducer) that is capable of achieving the goal of detecting the concentration of airflow laden with low concentrations of spherical particles less than 10 μm in diameter. The working principle of an acoustic transducer has been studied by a number of investigators; the success of detecting the existence of aerosol particles has also been shown [1–7]. A currently available and commercialized technology is that employed in an aerodynamic particle sizer (APS). The APS is a laser-based scattering instrument that costs between $40 000 and $50 000 each [8]. One known system (TSI Model APS 3310) also requires a knowledgeable user and consumes 950 W [8]. The current acoustic transducer involves no lasers and requires little power, as the airflow rate drawn through is no more than a few liters per minute. Relevant findings for the transducer [1, 2] are outlined below.

The present acoustic transducer used is shown in Figure 1 with all relevant dimensions. It is axisymmetric with a circular cross-section. The flow laden with aerosol particles was drawn past the transducer from left to right in the figure. The upstream portion of the transducer is the inlet tube. The inlet tube was joined by a capillary tube (1·98 mm in diameter) with a contraction. Particles tested included polystyrene latex (PSL) spheres [1] and graphite fibers with a diameter of 7·3 μm and length ranging from 1·59 to 25·4 mm (i.e., the aspect ratio equal to 218–3480 [2]). It was found that the inlet tube behaved like an organ pipe with one open end. The power spectra of the acoustical signal peaked at odd multiples of its natural frequency f_o ($f_o = c/4L$, where c and L are the speed of sound and the inlet tube length, respectively), which is approximately 900 Hz for the transducer shown in Figure 1 [1]. As the flow accelerates through the contraction, sufficiently large particles fail

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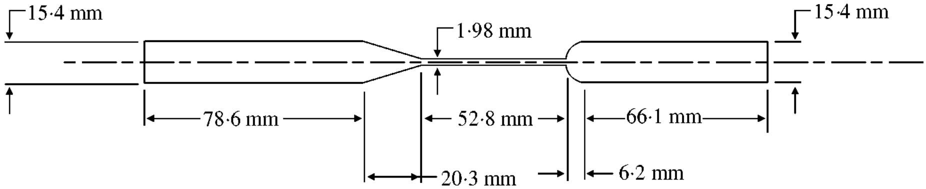

Figure 1. The acoustic transducer.

to follow the flow due to their inertia. As a consequence, the flow separates from the particle surface, which results in flow disturbances. This was believed to be the mechanism for acoustic emission within the inlet tube [1]. Since the lagging of the flow increases as the particle size is increased, the disturbance also increases with the particle size. Larger particles therefore give away signals with larger amplitudes and are easier to detect [1]. Spherical particles with diameters significantly less than 5·9 μm were difficult to detect, while graphite fibers with a diameter of 7·3 μm and various lengths were detectable [2]. Similarly, the higher the flow rate is, the larger the signal amplitude becomes for a given particle size, as the amplitude of the disturbance increases with the flow velocity for a given particle size [1]. An attempt to determine the aspect ratio of graphite fibers, which should help to determine particle shapes [2], proved successful.

Several unresolved issues, such as the mechanisms for acoustical signal generation, noted in references [3–6] were clarified and supported by the experimental data reported in references [1] and [2]. Based on the success reported in references [1] and [2], this study aims to answer the following questions: (1) what is the minimum detectable size with the current acoustical transducer? (2) can it accurately detect the particle concentration as low as a few tens of ppl? and (3) does the concentration thus determined depend on the size of the particle?

2. EXPERIMENT

The acoustical transducer (Figure 1) has been described in the introduction. For brevity, the reader is referred to reference [1] for the apparatus used to draw the airflow through the acoustic transducer. It is noted that naturally occurring particles with sizes larger than 0·5 μm were filtered [1]. A microphone was placed immediately outside of the inlet tube to pick up the acoustic signal. The time series of acoustic signals was recorded by an HP 35655A Dynamic Signal Analyzer, which was also shown on a digital storage oscilloscope (Tektronix 2201) for on-line observation.

Polystyrene latex (PSL) spheres were used. Two nominal particle sizes (5·9 and 9·6 μm) were chosen. The particle concentration was determined by knowing the airflow rate and the number of the acoustic signatures over a period of time. The flow rate was measured by a rotameter, placed in the line of the flow, and was maintained at 4·4 l/min during the experiment. The concentration thus obtained was compared with that determined by APS; the size of particles was also confirmed by APS.

3. RESULTS AND DISCUSSION

Typical acoustical signals, composed of high-frequency large-amplitude pulses and low-frequency background noise, are as depicted in Figure 2. Each pulse train represents

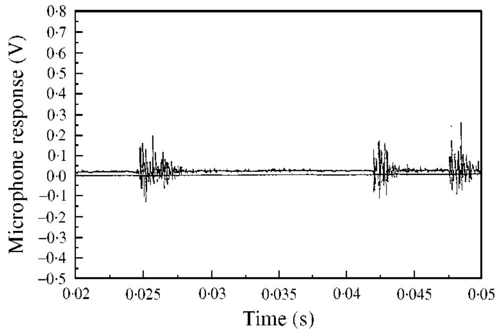

Figure 2. A typical pulse train of acoustic signals generated by particles passing through the acoustic transducer shown in Figure 1.

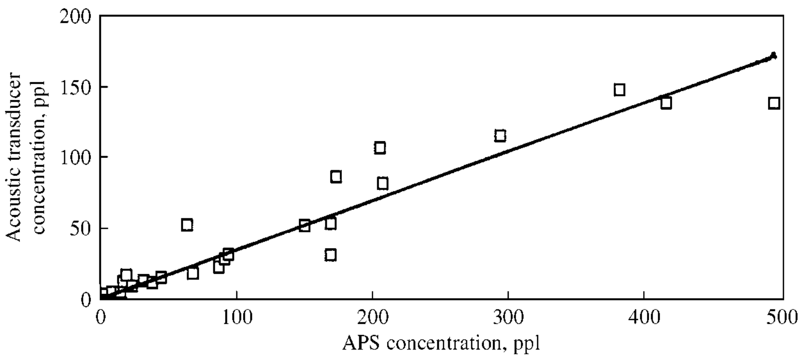

Figure 3. Particle concentration determined by the acoustic transducer versus that determined by the laser-based aerodynamic particle sizer (TSI Model APS 3310). The nominal particle size is 5·9 μm.

a particle passing from the inlet tube through the contraction into the capillary. In fact, there was an audible popping noise as particles entered the transducer. When expanded, one can see that the particle signal begins with a negative voltage output [1]. Since the particle concentration was low (i.e., a dilute particle-laden flow), no overlapping of particle signals was observed. It was therefore easy to count the number of pulses over a long period of time. Since the flow rate is known, the particle concentration can be calculated.

During the experiment, particles with diameters less than 5·9 μm were not easily detected. Figures 3 and 4 show the particle concentration detected by the acoustic transducer versus that determined by APS for particle sizes of 5·9 and 9·6 μm respectively. The experimental data appear to fall around the solid line in both figures, which represents the best linear fit. For 5·9 μm particles, the concentration determined with the acoustic transducer appears to be as high as 45% of that determined by APS; it is approximately as high as 90% for the 9·6 μm particles. These results confirm that larger particles are easier to detect as they cause larger flow disturbances. The results of Figures 3 and 4 also suggest that particle concentrations as low as a few ppl (based on the APS measurement) can be detected.

Although there is no sharp cut-off size below which no signal can be observed, the probability of detecting a particle increases with particle size. Based on the results of Figures 3 and 4, it would be small wonder that nearly all particles can be detected for sizes greater than 10 μm. For dilute particle-laden air, the proportionality constant was found to be relatively independent of the flow rate. This is suggested, again, by the fact that data in

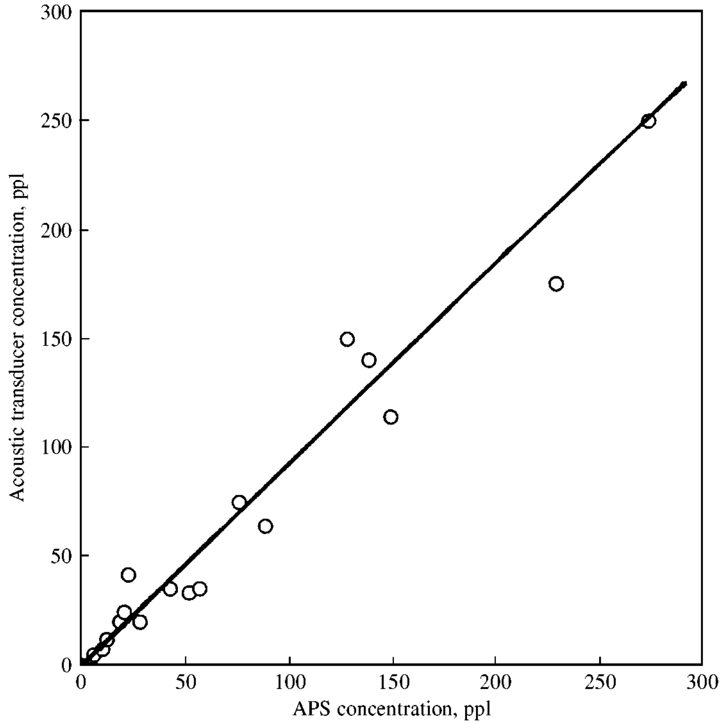

Figure 4. Particle concentration determined by the acoustic transducer versus that determined by the laser-based aerodynamic particle sizer (TSI Model APS 3310). The nominal particle size is 9·6 μm.

Figures 3 and 4 fall around the straight solid lines. With proper calibration (for proportionality constant), the acoustic transducer can be used to accurately determine particle concentration. A single-point calibration should suffice for practical applications.

As mentioned in the introduction, the ability of an acoustic transducer to detect particles depends on both the flow rate and the acceleration of the flow through the contraction. It is, therefore, possible to construct an array of transducers with different contraction ratios with various transition lengths between the inlet tube section and the capillary. Each of these transducers can be operated with various flow rates. For different combinations of transducers and flow rates, there will correspondingly be different minimum detectable particle sizes. Taking the differences of the number of particle counts of each transducer would effectively determine the number of particles in each size range.

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