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SHAPE DETERMINATION OF AEROSOL PARTICLES USING AN ACOUSTIC TRANSDUCER

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1. INTRODUCTION

A recent study revealed how an acoustic transducer detected spherical particles [1]. The particles tested were polystyrene latex (PSL) spheres. The acoustic transducer used is as sketched in Figure 1, with all the relevant dimensions. Particles carried by air flow were drawn through the transducer. The sections of the acoustic transducer, in the order of the flow direction (from left to right in Figure 1), are the inlet tube, the contraction, the capillary tube, and the expansion, followed by the outlet tube. For experimental details, the reader is referred to reference [1]. The key reported findings are as follows. First, the acoustic signal was caused by the inability of the particle to follow the accelerating flow in the contraction. At that location the particle was believed to cause flow disturbances such as flow separation or begin to experience unsteady or vibrating motion due to acceleration. These events led to acoustic radiation, which was amplified by the acoustic transducer. The inlet tube acted in a way similar to an organ pipe with one open end. In the study, the experimental conditions precluded existence of shock waves believed by other researchers to be responsible for the acoustic radiation [2]. Secondly, the frequencies of the detected signal were found to be consistent with the fundamental frequency (f_0) and harmonics with odd multiples of f_0, i.e., $3f_0$, $5f_0$, ... , as expected for an organ pipe with one open end. These observations were also documented for acoustic transducers of several configurations and dimensions [1, 3]. Third, acoustic signal traces and power spectra were similar for all particles investigated. Finally, the signal amplitude was found to increase with the flow rate but appeared to be independent of particle size. The reader is referred to references [2, 4–7] for the development and applications of the acoustic transducer dated from the 1960s. Although not reported in reference [1], graphite fibers with 7·3 mm diameter and aspect ratios exceeding 200 were also drawn through the acoustic transducer [3]. The above observations for PSL spheres were in general true for these graphite fibers.

One interesting question naturally arising is: For a given transducer how would the signal characteristics depend on the shape of the particle? The experimental effort described below was an attempt to establish such a capability. It is worthwhile noting that the first

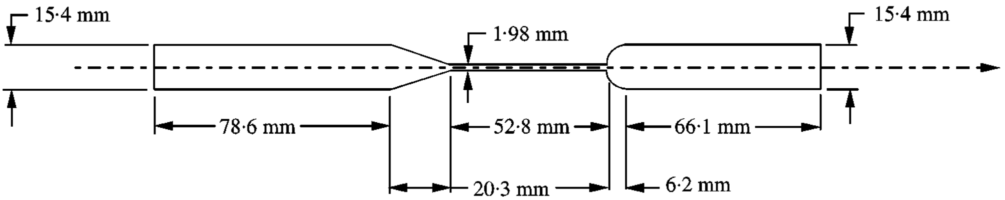

Figure 1. The acoustic transducer.

subharmonic peak at $3f_0$ of the power spectra due to spherical aerosol particles appeared to be the most energetic among all peaks including the fundamental frequency [1,3]. A preliminary study showed that with graphite fibers, the peak in power spectra is the highest at the fundamental frequency f_0. It was then decided to further investigate such a difference in more details.

2. EXPERIMENT

The acoustic transducer is as sketched in Figure 1, the same as the one used in reference [1]. Detailed experimental set-up and procedures are similar to those in reference [1]. A pump was used to draw air laden with aerosol particles through the acoustic transducer; the flow direction was from left to right in Figure 1. The particles used for this study included PSL spheres and graphite fibers. These fibers had six different lengths: 1·588, 3·175, 6·35, 12·7, 19·05, and 25·4 mm. These fibers are cylindrical in shape and all have the same diameter of 7·3 μm. These fibers thus have aspect ratios ranging over more than a decade. The microphone for signal detection was placed just outside the inlet of the acoustic transducer. The signal was fed to the storage oscilloscope and the FFT analyzer for data storage and analysis. It is known that changing the position of microphone within the inlet tube does not qualitatively alter the signal or its spectral content [1].

The flow rate carrying the graphite aerosol particles was set at 39 l/min. Like changing microphone position, changing the flow rate does not affect the qualitative results of the signal [1]. The pressure at the inlet of the transducer was that of the ambient, i.e., 101·3 kPa and the pressure drop was about 10 kPa across the capillary tube (1·97 mm in diameter, as shown in Figure 1). It is believed that there were no shock-related phenomena and the acoustic signals were generated by the aerodynamic disturbances of the particles, as concluded in reference [1].

3. RESULTS AND DISCUSSION

First of all, the acoustic signal trace and the power spectrum of 50 μm PSL spheres are reported in Figures 2(a) and 2(b). It is noted from Figure 2(a) that the acoustic signal begins with a depression in pressure, followed by oscillations over a period typically of a few milliseconds. Although not reported here, similar results were observed for smaller SPL spheres. It is clear from Figure 2(b) that the fundamental frequency (f_0) is about 900 Hz, with subharmonic peaks at approximately 2700 Hz ($= 3f_0$), 4500 Hz ($= 5f_0$), and 6300 Hz ($= 7f_0$). Because the acoustic transducer behaves like an organ pipe with one open end, the subharmonic frequencies have values that are odd multiples of the fundamental frequency. The fundamental frequency calculated for such an organ pipe with the length equal to that of the inlet tube shown in Figure 1 confirmed this observation [1]. The power spectra of signals produced by 15 μm PSL spheres are presented in Figure 3. Spectral peaks for 15 μm

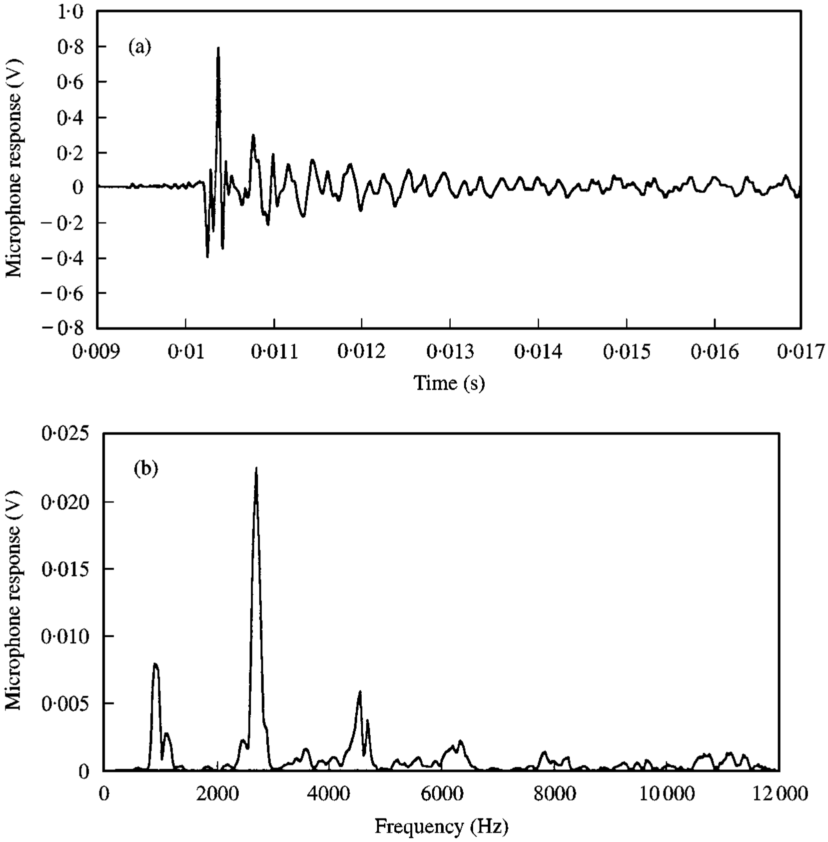

Figure 2. (a) Typical time trace of an acoustic signal produced by a particle passing through the acoustic transducer shown in Figure 1; the trace shown is for 50 μm PSL spheres. (b) Spectral distribution of the acoustic signal.

PSL spheres were found to be located at nearly the same frequencies as those for 50 μm PSL spheres (Figure 2(b)). For both 15 and 50 μm PSL spheres the maximum peak occurs at a frequency $\approx 3f_0$. For these particle diameters, the magnitude of the dominant peaks are about three times the peak located at the fundamental frequency, as shown in Figures 2(b) and 3.

Time traces of acoustic signals for all the six graphite fibers are very similar to those for PSL spheres. Typical results (for 3·175 mm fibers in this case) are as shown in Figures 4. Similar to those for spherical PSL particles [1], the acoustical signal begins with a decrease in pressure and rapidly decays within a few milliseconds. During the course of this investigation, several other types of particles were also used for observation. All the acoustical signal traces would begin with a decrease in pressure, as in Figures 2(a) and 4, and are not reported for brevity. However, the power spectra of graphite fibers exhibit some discernible differences that may help the identification of shapes of aerosol particles. These results are presented in Figures 5(a)–5(f).

As shown in Figures 5(a)–5(f), the fundamental frequencies for the six fiber lengths investigated are all nearly the same as those for spherical PSL particles (Figures 2(a) and 4), at approximately 900 Hz. All the spectral peaks for the six lengths were also observed at frequencies that are odd multiples of the fundamental frequency, again agreeing with the results for PSL spheres (see Figures 2(b) and 3). It can be clearly seen in Figure 5(a)

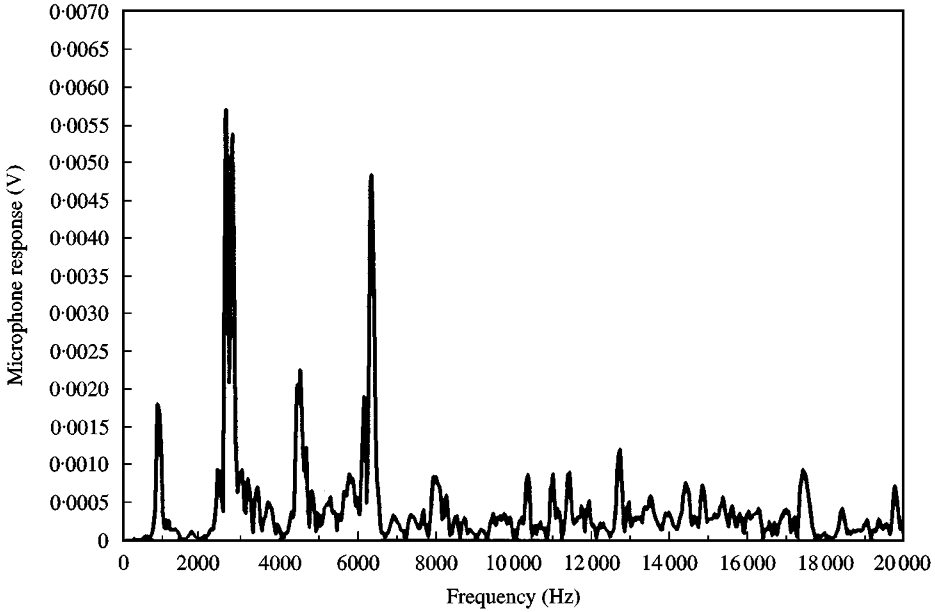

Figure 3. Spectral distribution of an acoustical signal produced by a 15 μm PSL spheres.

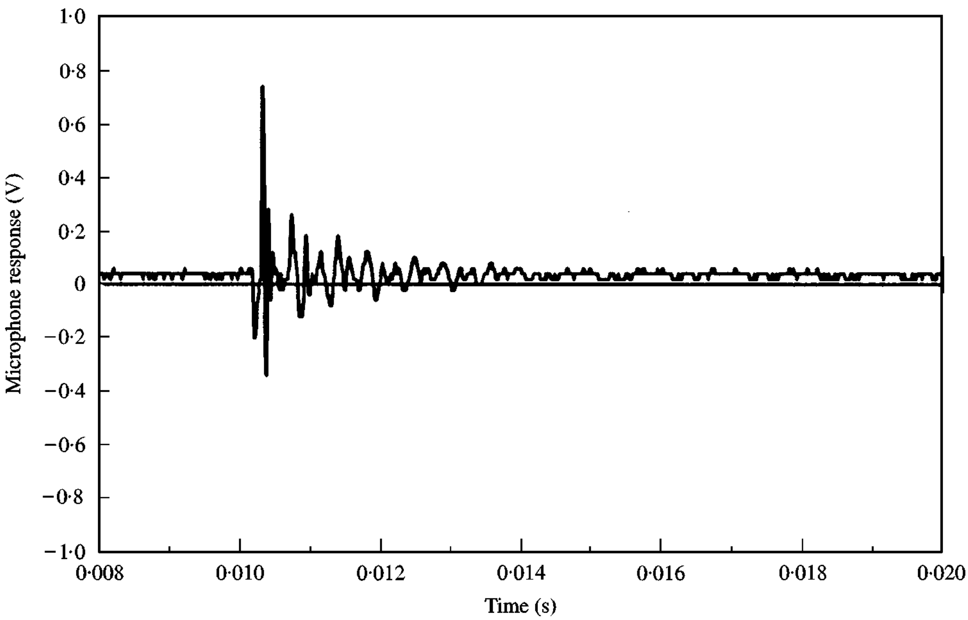

Figure 4. Time trace of an acoustic signal produced by a 3·175 mm graphite fiber. Note that it is qualitative similar to that for spheres as shown in Figures 2(b) and 3. Also note that fibers having different lengths produce similar signals.

that 1·588 mm fiber particles (which have the smallest aspect ratio, ≈ 220, in this investigation) produced the highest peaks at $3f_0$. The ratio of the magnitude at $3f_0$ to that at f_0 is approximately equal to 3. This is similar to the results for spherical PSL particles (i.e., Figures 2(b) and 3). It is speculated that the graphite fiber with small aspect ratio produce spectral distributions similar to those produced by spherical particles both qualitatively and quantitatively, with the most dominant peak at $3f_0$.

However, for fiber length equal to 3·175 mm, the peak at the fundamental frequency f_0 became slightly more dominant than the one at $3f_0$ (Figure 5(b)). This dominance is more

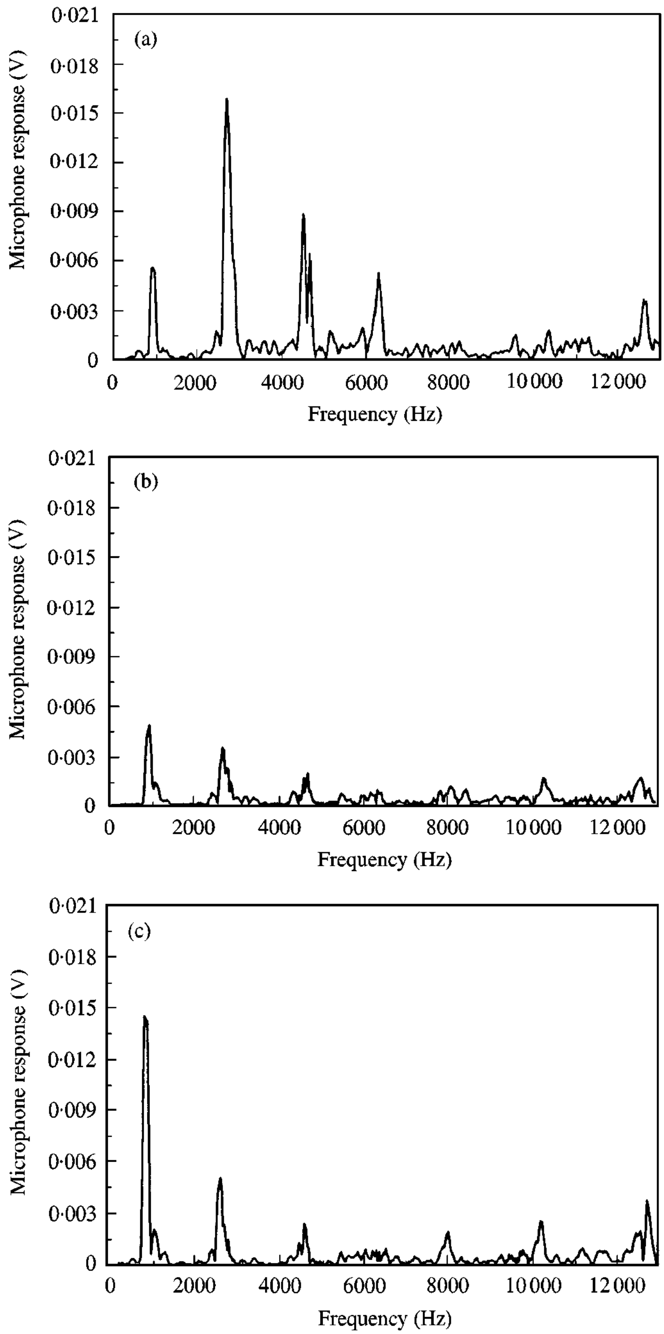

Figure 5. Spectral distribution of an acoustic signal produced by graphite fibres of (a) 1·588, (b) 3·175, (c) 6·35, (d) 12·7, (e) 19·05 and (f) 25·4 mm

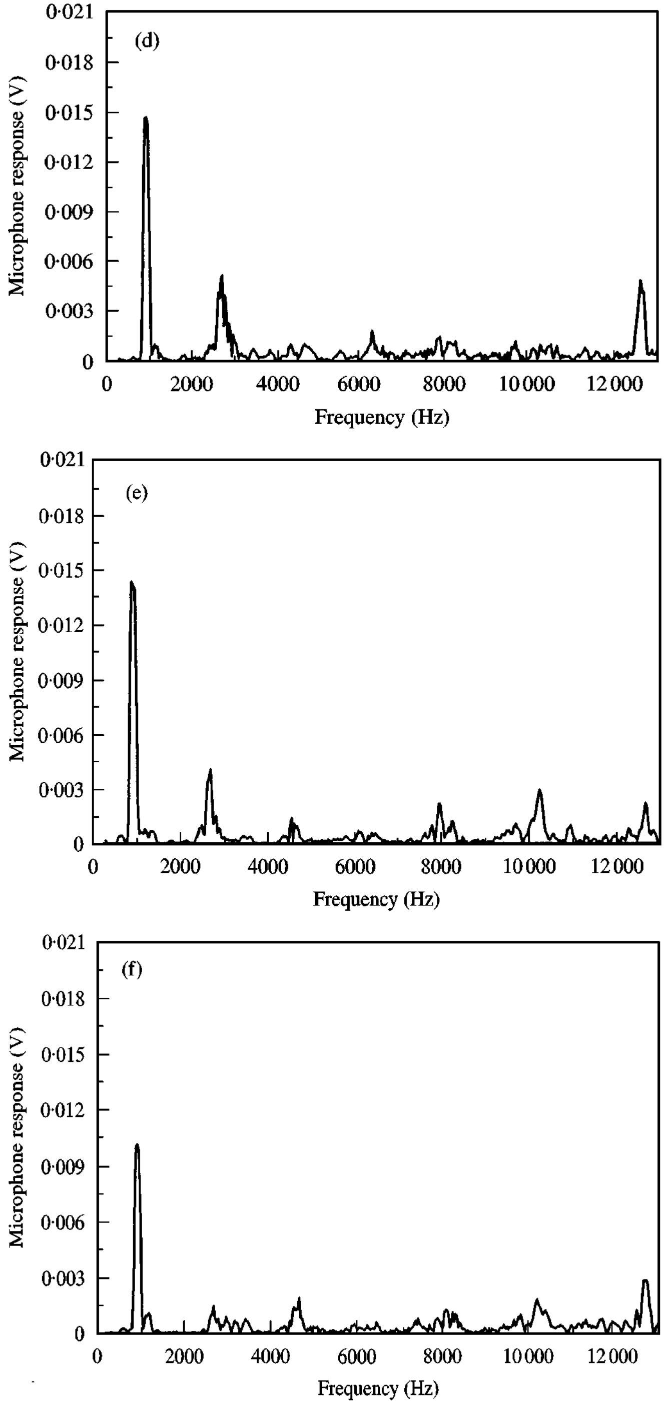

Figure 5. Continued.

clearly seen for fibers longer than 3·175 mm, as shown in Figures 5(a)–5(f). Results for graphite fibers longer than 3·175 mm are therefore qualitatively different from those for spherical PSL spheres (Figures 2(a) and 4). Quantatively, the ratio of the spectral magnitude at $3f_0$ to that at f_0 for longer fibers is approximately $\frac{1}{3}$ or less. This ratio is nearly a 10-fold decrease from that for 1·588 mm fibers. This change was found to be quite repeatable between seven-fold and 12-fold during the experimental investigation. It is noted that the absolute magnitude of the spectral peak may not be a good indicator of whether the aerosol particle is a spherical PSL particle or a graphite fiber. This is because the amplitude of the spectral peak does not appear to be dependent on the fiber length, nor does it depend on the particle type (i.e., spheres versus cylindrical fibers), as can be seen from Figures 2(b), 3, and 5(a)–5(f). The signal amplitude such as those reported in Figures 2(a) and 4 would not serve as a good indicator, either. This is because no definite trend of the magnitude as a function of the particle size or shape was observed during the experiment.

4. SUMMARY

The results of this investigation suggest that it is possible to discriminate whether an aerosol particle is spherical or cylindrical in shape using the acoustic transducer described in Figure 1. Cylindrical fiber particles with sufficiently large aspect ratio (greater than 500 in this study) yield dominant peaks at frequencies different than those for spherical particles. However, the present study cannot provide quantitative information regarding the value of the fiber aspect ratio. Further research is needed to shed light on the mechanism causing differences in acoustic power spectra of spherical particles and fibers with large aspect ratios.

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