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ACOUSTIC AGGLOMERATION OF POWER PLANT FLY ASH

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INTRODUCTION

Acoustic agglomeration is a method of preconditioning the aerosols generated by, for example, coal fired utility boilers and also the products of combustion of fluidized bed coal combustion systems. After a first pass through conventional particle removal methods such as electrostatic precipitators, bag houses or scrubbers to remove the larger particles, the large number (about 80% by number) of remaining submicron particles are agglomerated to micron size for more efficient final removal by another pass through such conventional methods as already listed since these devices are notoriously inefficient in the removal of submicron sized particulates. It is known that these fine particles are particularly injurious to the human respiratory system. Thus, an economically and technically viable method which could precondition the power plant effluents by increasing the size of the submicron size particulates through coagulation to the 10 micrometer size class would enhance the overall effectiveness of the conventional particle removal techniques. For the case of the pressurized, fluidized bed combustion systems with the intent of using the products of combustion directly on gas turbines the removal of the remaining submicron particles after cyclone treatment becomes particularly critical in order to increase turbine life to acceptable values. If these tiny particles are not removed by first acoustic agglomeration followed by several stages of cyclones, the turbine blades and vanes would erode reducing cycle efficiency, thus in fact reducing turbine life.

High intensity (160 dB), high sonic frequency (3000 Hz) acoustic fields have been known to cause significant agglomeration of submicron particles as a result of many investigations in Germany, Canada, Russia and the United States dating back to the 1920's with revivals in the 1950's and again in the present as a result of increased awareness of environmental clean up needs and hot gas clean up requirements.

THE NATURE OF ACOUSTIC AGGLOMERATION

The underlying theory of acoustic agglomeration is very complex. Simply stated, the high intensity acoustic field causes particle oscillations and particle drifts which result in particle collisions and particle adhesion ergo the formation of agglomerates. The individual forces on the particle can be divided into viscous drag forces, which are the result of acoustic velocities; hydrodynamic turbulence; acoustically generated turbulence; acoustic streaming (the latter two being nonlinear acoustic effects); forces due to Brownian motion; radiation pressure caused forces; forces due to small scale viscosity variations; Oseen forces caused by second order viscous effects and hydrodynamic forces from flow between closely spaced particles. The flow processes are on one hand essentially diffusional in nature recognizing the coming together of particles from essentially random relative motion and on the other hand we recognize the collisions between slowly drifting large particles with oscillating small particles, in effect a "sweeping out" called the orthokinetic effect.

A key feature of any model of the agglomeration process in the process is the complete understanding of the acoustic field meaning the local velocity fluctuations, and the temporal and spacial acoustic intensity variations. In this brief paper, I would like to report the results of one basic investigation and some agglomeration results with fine fly ash aerosols.

ACOUSTIC GENERATED TURBULENCE

Several investigators (Mednikov 1965, Shaw 1982) describe a process of generating significant random motions in high intensity (160 dB) acoustic fields which in turn are proposed as major causes of acoustic agglomeration. A series of recent tests at Penn State Noise Control Laboratory in a small scale (0.3x0.6x0.025m) chamber equipped with movable hot wire anemometer probes and acoustic pressure probes with acoustic levels up to 168 dB and frequencies in the 1000-4000 Hz range has shown that the velocity spectra do contain some random motion. The dominant velocities occur at the excitation frequency and its harmonics as shown in Fig. 1 with the randomness developing about these frequencies. The rapidly decreasing random velocities up to 1000 Hz are caused by acoustic streaming as would be predicted for the high acoustic levels, the location of the two sources and the geometry of the chamber. Also the "turbulence" is limited to certain regions amounting to less than 20% of the area. We were further able to simulate this effect electronically by generating an intermodulation distortion phenomenon which simulates the interaction of the low frequency "noise" with the harmonics resulting in the noted thickening and rise of the random velocities at the harmonic frequencies. By studying the energy dissipation rate we could only conclude that the energy in the random frequencies is 2 to 3 orders below the energy in the fundamental and harmonic frequencies. We suggest therefore that acoustic turbulence may not be a significant factor in acoustic agglomeration.

AGGLOMERATION RESULTS

Very encouraging results were obtained on our intermediate temperature agglomerator. A 2.5 m long, 20 cm diameter schedule 40 steel pipe contains a slowly convecting aerosol fly ash. The pure tone sound energy is provided by a 600 acoustic watt siren. Frequency is controlled by siren speed. The aerosols particle size distribution is obtained by isokinetic sampling and an Anderson Mark III impactor. Exposure time to sound is controlled by convection velocity. A typical example of such test results is given in Fig. 2. On the ordinate we have a measure of the percent differential mass in each size group, on the abscissa we plot the particular stage's midpoint aerodynamic diameter on a logarithmic scale. The acoustic levels are all in the 160 dB range showing very substantial agglomeration of the small particles into the 10 micron range and larger. The results must be compared with the particle size distribution with no sound. This particular result shows the effect of frequency. Although the plot for 1290 Hz has a level of 166 dB the higher frequency plots at somewhat lower acoustic levels show better agglomeration.

From the results of in excess of 100 tests at varying operating variables of sound level, frequency, loading and exposure duration we can draw the following conclusions: 1) For the fly ash aerosols with a mean size of about 3 microns there appears to be an optimum frequency of about 2800 Hz. 2) Increasing sound levels up to about 165 dB give increasing agglomeration. There are indications that further increases in acoustic pressure will result in de-agglomeration. 3) Increasing residence times up to about 15 seconds give increased agglomeration. At the highest levels increases above 10 seconds may give poorer results. 4) For dust loadings from 1 g/m^3 to 30 g/m^3 the higher the loading the better the agglomeration. 5) From limited tests at elevated temperatures there are indications of slightly reduced agglomeration with increasing temperatures.

All the resulting trends agree with agglomeration theory.

CONCLUSIONS

The theoretical work and experimental results show that substantial acoustic agglomeration of submicron and micron sized fly ash particles can be accomplished at high but practical acoustic levels and at achievable frequencies. The agglomerates appear to be sufficiently robust to withstand the rigors of flows in cyclones. Acoustic velocities and drifting from acoustic streaming and convention flows as well as several other nonlinear acoustic phenomena appear to dominate the agglomeration processes with acoustically generated turbulence over broad frequency ranges not taking a significant part.

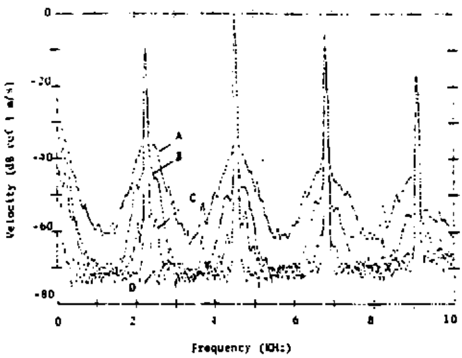

Fig.1. Velocity spectra at the same measurement location and frequency of excitation (2262 Hz) but at different sound levels. The sound pressure level at the corner of chamber and at the location of measurement were: Spectrum A - 168 and 160 dB; Spectrum B - 166 and 158 dB; Spectrum C - 164 and 155 dB; Spectrum D - 162 and 153 dB.

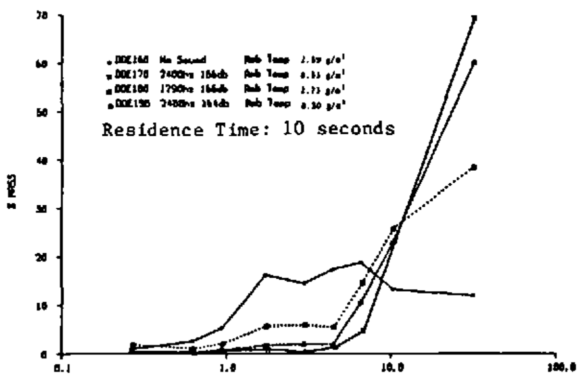

Fig.2. Acoustic agglomeration results with fly ash aerosols at ambient temperatures.

20. PHYSICAL PHENOMENA

21. Physical mechanisms of noise generation
22. Natural sources of noise
23. Propagation, transmission and scattering
24. Sound propagation in the atmosphere