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REMOVAL OF CHARGED POWDER DEPOSITS BY HIGH INTENSITY LOW FREQUENCY SOUND: THE ROLE OF INERTIAL AND DRAG FORCES

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Abstract

Powders can be dislodged from surfaces by inertial or drag forces. Inertial forces are primarily generated by vibrating the coated surface. In industry, inertial forces are generated by shaking (or rapping) the coated surface, such as a collection plate of an electrostatic precipitator. Drag or viscous forces result from exposure of the powder particles to fluid flow, including sound fields. Commercially available sonic cleaning systems are presently available but are not always as efficient as rapping systems. In a series of laboratory experiments, electrostatic deposited powders were exposed to controlled vibration from which estimates of powder bonding forces were possible. The same powder coatings were exposed to low frequency sound the level and frequency of which could be adjusted until the powders were de-bonded. The relationship between the bonding forces and acoustic de-bonding forces is explored. It is demonstrated that an estimate of the required de-bonding sound pressure level is possible from knowledge of the de-bonding vibration level and a third factor, which depends on the drag characteristics of the powder particles.

INTRODUCTION

Electrostatic precipitation is an efficient means of reducing particulate emissions from flue gases from large coal fired power stations. The process exploits the difference in electrical properties between the particulate and the gas, allowing dust particles to become charged and directed using strong electric fields. The collected dust forms layers on large earthed collection plates. After a period of build-up the dust must be removed before the thickness of the layer reduces the efficiency of the system. The most common method of removal is by rapping the plates using large metal hammers [1]. This method is efficient but can lead to mechanical damage to the system.

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An alternative to rapping is the use of high intensity low frequency sound to remove the collected dust [2]. Such acoustic cleaning systems are inexpensive, easy to run and maintain, and can operate in parallel with the main process [3]. However the use of acoustic cleaners in precipitators is not common and the efficiency of the technique is variable. The aim of this work is to assess the sound pressure level and frequency content of sound required to de-bond electrostatically deposited fly-ash. The approach adopted was to first assess the adhesion forces (between fly-ash and surface) and cohesion forces (within the fly-ash) by means of inertial effects in a vibration rig. The second step then was to generate sufficient sound to de-bond the same ash plate combinations. The relationship between the acoustic and vibration forces then is explored.

EXPERIMENTAL DETAILS

The investigation involved electrostatically coating an aluminium cube with fly-ash in a manner similar to that in real electrostatic precipitators. A calibrated vibration table then was employed to remove the layers at selected frequencies. Finally, the coated cube was subjected to high sound pressure levels at selected frequencies [4].

The coated cube was placed on the calibrated vibration table and at a selected frequency the acceleration was increased until the fly-ash layer was removed from a vertical surface of the cube. The removal was usually sudden, rather than gradual, and results were repeatable within +/- 2dB (see figure 1).

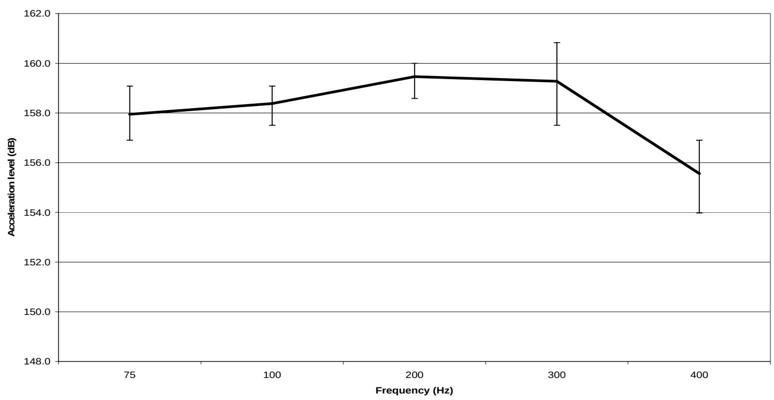


Figure 1 Range of de-bonding acceleration levels for five tests of the same ash

The same fly-ash plate combinations were then placed in the high intensity wave tube system. A travelling wave condition was obtained by means of acoustic wedges at the open end of the tube (see figure 2). The sound pressure level at a selected frequency was increased until de-bonding occurred. Measurements were repeated four times at each frequency and results were repeatable within +/- 3dB (see figure 3). The measurement frequencies of 75Hz, 100Hz, 200Hz, 300Hz and 400Hz corresponded to the measured frequencies of the vibration tests conducted previously and with the operating range of commercially available acoustic cleaning systems. (N.B. the low frequency range of operation of commercial cleaners allows penetration of the sound to distant and partially screened area of the precipitator housing, which often are of dimensions of the order 15m x 15m x 5m. Higher frequency sources, including ultrasonic sources, can be more effective but over limited distance).

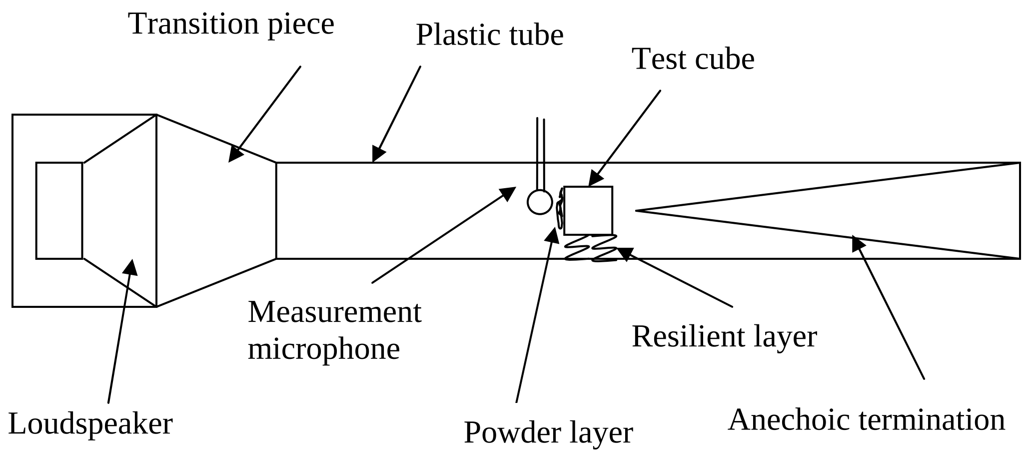


Figure 2 High sound intensity wave tube

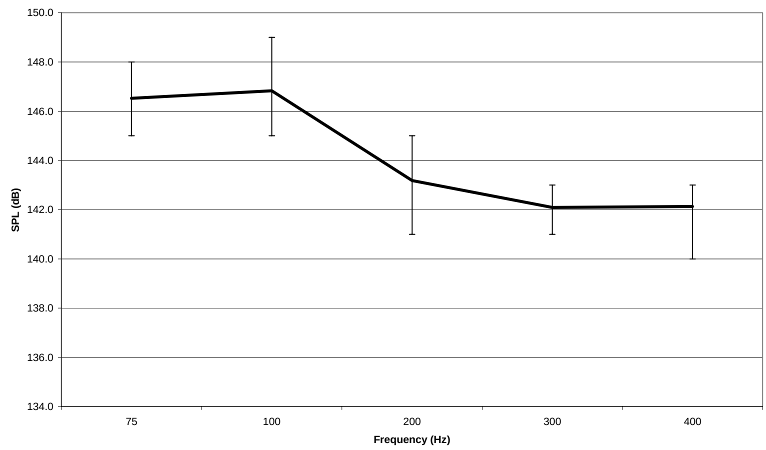
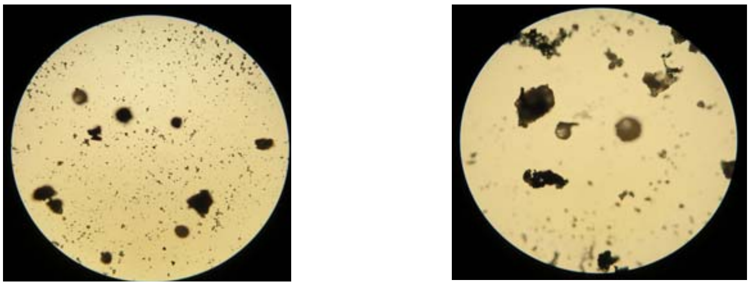


Figure3 Range of de-bonding sound pressure levels for five tests of the same ash

Materials used in the study

The dusts used in the investigation are samples of fly-ash from the precipitators of five large coal burning power stations within the UK. Micrographs of typical samples from two power stations are shown in Figure 4. The compositions of the dust are similar and comprise irregular shaped particles with a broad size distribution. The larger particles are approximately 30-50 microns across their largest dimension. The sample also contains fine powder particles of approximately 5 microns diameter. The fine powder adheres to the larger particles, forming asperities which enhance the bonding between the larger particles to form agglomerates.



50µm —   50 µm —

Figure 4 Micrographs of fly-ash from two power stations

The similarity of the particles making up the five samples is surprising as the five fly-ash samples were obtained from five different power stations, which are supplied with different types of coal.

Dust layer removal by vibration

On placing the coated cube on the calibrated shaker table, the acceleration level was increased until the layer detached from a vertical surface. In general the detachment was catastrophic in nature, leaving a residual layer of approximately 50 microns thickness. In figure 5 is shown the vibration level at which de-bonding occurred.

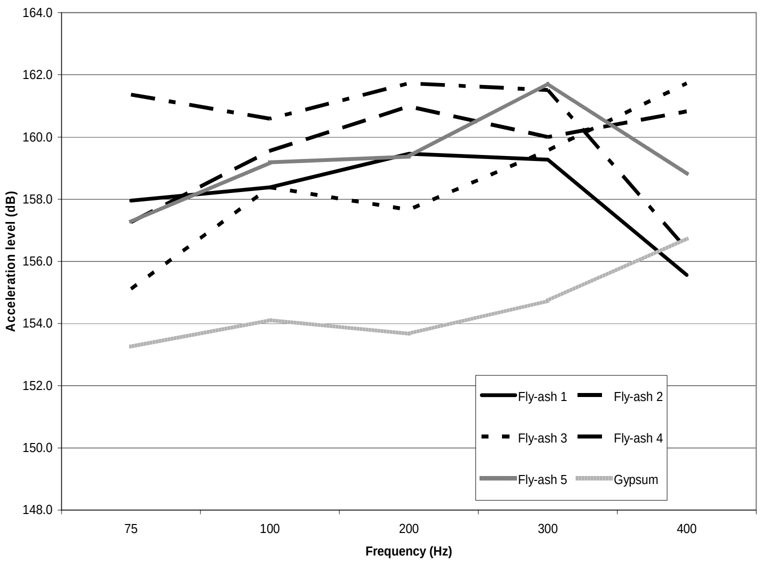


Figure 5 De-bonding acceleration levels for fly-ash from five power stations. Also shown are values for Gypsum (80µm).

The results are consistent in that the values are frequency invariant, within the range of repeatability, for frequencies below 300 Hz. Above 300 Hz, a reduced level is indicated but this is not consistent across the five samples. In general, the powders behave the same, within a range of 4 dB.

If it is assumed that the powder layer behaves as a rigid mass then the total de-bonding force is obtained directly from the product of the removal acceleration and the mass of the deposited powder layer. The particle bonding force can then be estimated by dividing the measured inertial force by the number of particles in contact with the surface or each other (the last column in table 1).

Table 1: Powder bonding forces

Powder	Layer mass g	Acc. m/s^2	F inertial N	F bonding 10^{-7}N
Dust 30um	6	93	0.56	2.1
Gypsum 80um	6.2	54	0.33	8.8

Adhesive and cohesive forces

Hein[5] gives the adhesive force between a sphere and plate in terms of the Van der Waals force as

$$F_{ad} = \frac{A_{12}}{12} \times \frac{dp}{a_0^2} \quad (1)$$

Likewise, the cohesive force between particles as

$$F_{coh} = \frac{A_{11}}{24} \times \frac{dp}{a_0^2} \quad (2)$$

A_{12} is the Hamaker constant between the plate and the powder, A_{11} is the Hamaker constant between powder particles, *dp* is the particle diameter, a_o is the distance between particles. The adhesive and cohesive forces, from equations 1 and 2, are shown in Table 2. Also shown is a value obtained from the inertial force in Table 1.

Table 2 Adhesive and cohesive forces

Powder	Adhesive force x 10^{-7}N	Cohesive force x 10^{-7}N	From inertial force x 10^{-7}N
Fly-ash(30 μm)	8.7	2.9	2.1
Gypsum(80 μm)	19.8	5.2	8.8

The predicted adhesive force between the plate and the deposited layer is greater than the cohesive force between particles in the layer. The estimated values, from the vibration measurements (the last column of Table 2) are of the same order as the predicted cohesive forces, both for the fly-ash and the gypsum powder. Equations 1 and 2 include only the effect of Van der Waals forces. Electrostatic and mechanical forces between the layer and the plate can be expected to contribute but results indicate that the Van der Waals forces are dominant.

Removal by sound

The coated cube was placed in the high intensity wave tube 2m from the drive unit. The de-bonding sound pressure level was measured by a microphone mounted near to the cube. The cube was resiliently mounted to reduce direct vibration excitation, and measured accelerations were 30 dB below that required to remove the fly-ash layer when the cube was directly shaken. In Figure 6 are shown the de-bonding sound pressure levels for the five dusts investigated. Again the results are within a range of 4 dB at each frequency. There is a consistent decrease in level with increased frequency, of the order of 3 dB per octave.

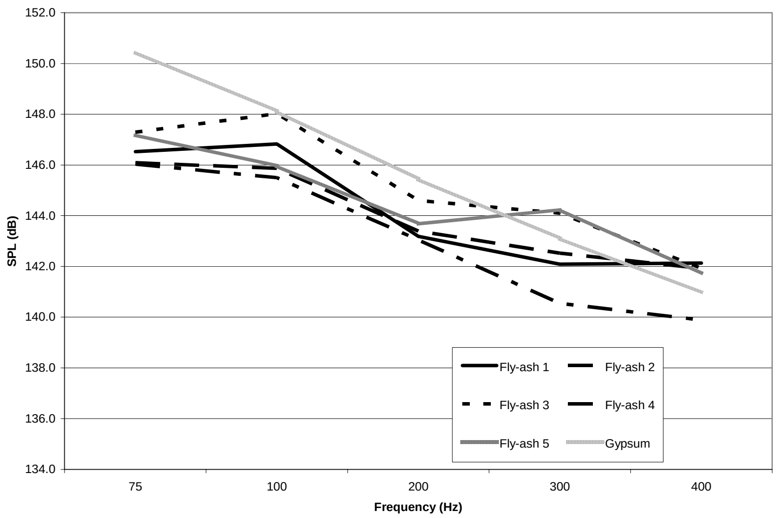
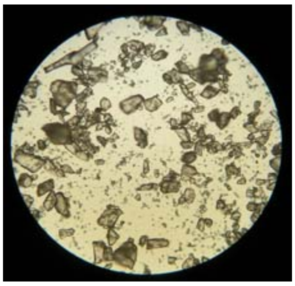
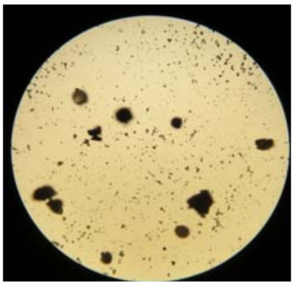


Figure 6 De-bonding sound pressure level of fly-ash from five power stations. Also shown are values for gypsum (80μm)

INTERPRETATION OF RESULTS

The Gypsum powder was included in the study as it has significantly different powder characteristics (as shown in Figure 7). The de-bonding acceleration for the Gypsum powder is consistently lower than for fly-ash, by about 4dB (see Figure 4). As the mass of the ash and Gypsum layers were similar the inertial de-bonding force for Gypsum must be less than for fly-ash. It might have been assumed that a lower sound pressure level would be required to remove the Gypsum powder. Figure 6 does not show this to be the case. Removal by acceleration is likely to be mainly by inertial forces whilst removal by sound is likely to be a combination of drag and inertial forces. Therefore in order to predict the sound pressure level required to remove a powder layer from acceleration measurements an additional factor, based on powder characteristics, is required. This factor might be inferred from micrographs of the powder.





100 μm —   *50μm* —

Figure 7 Micrographs of Gypsum powder (left) and fly-ash (right)

The high repeatability of the de-bonding acceleration and onset sound pressure levels for individual fly-ash samples and the small spread in results for different samples indicates that the fly-ashes appear to behave as a sample from the same population. The ash also had the same shape and size distribution, from inspection of the micrographs. This is somewhat surprising as the five power stations which provided the ash burned different coal compositions in different boiler/burner systems. This suggests that a general specification for onset sound pressure level at a particular frequency is possible for electrostatically deposited fly-ash.

CONCLUDING REMARKS

The fly-ash samples, from five power stations, had similar physical characteristics. The dusts therefore behave as a family and have a narrow range of de-bonding accelerations and onset sound pressure levels. Fly-ash having similar physical characteristics to those tested will have similar onset sound pressure levels.

The de-bonding acceleration for fly-ash is frequency invariant.

The trend in de-bonding sound pressure level is of the order of 3 dB per octave.

To predict onset sound pressure level from de-bonding acceleration for physically different powders a new factor based on powder characteristics is required. This is illustrated by the gypsum powder results in which a low de-bonding acceleration did not correspond to a low onset sound pressure level.

The remaining objective of this work is to refine the laboratory set-up to more closely simulate conditions found in real electrostatic precipitators. This will involve investigating the effect of surface roughness on the onset sound pressure level and testing sections of precipitator collection plates.

The voltage on the discharge electrode remains when the precipitator is operating and may produce an additional residual clamping force. This will be considered by investigating the effect of varying the high voltage supply to the discharge electrode (say 10kV to 50kV) on the inertial de-bonding force.

A practical implication of the work concerns the attainable sound pressure levels on site. Commercially available air-driven horn units will be considered in terms of number, location and operating conditions, required to achieve levels of the order of 145 dB at remote points in the precipitator housing.

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