COMBINED EFFECTS OF MECHANICAL AND ACOUSTIC VIBRATIONS ON FLUIDIZATION OF COHESIVE POWDERS

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Abstract

Bubbling fluidized bed experiments were performed on powders ranging in size from 0.012 to 15 μm, with room temperature air as the fluidizing gas. Powders this fine are cohesive in nature and typically form clusters of particles, which can interfere with the fluidization process and, in some cases, result in channeling and spouting, instead of bubbling.

Previous studies in our laboratory explored the use of high intensity acoustic vibrations to disrupt the interparticle forces and decrease the superficial gas velocities needed to achieve minimum fluidization. The present paper deals with the simultaneous use of acoustics and horizontal mechanical vibrations to achieve fluidization. Experiments were run with the bed equipped with a loudspeaker at the top of the freeboard and a motor-driven mechanism to impart horizontal vibrations to the fluidized bed column. Results are presented on the effects of these two types of vibrations on minimum fluidization.

Introduction

Interparticle forces can affect gas fluidization of fine powders in various ways. Some micron-size particles in the Geldart C range form channels and spouts, instead of the bubbling which occurs for larger particles at velocities above minimum bubbling. Recently published results of experiments with nanoparticles show these form large particle agglomerates, which are then fluidized as Geldart A or B powders. Numerous papers have been published in which the effects of mechanical vibration of the bed vessel on minimum fluidization and bubbling behavior of fine particles are reported. Other papers have reported on the application of high intensity acoustic vibrations to cause oscillations of the fluidizing gas and thereby promote bubbling fluidization. The present paper describes experiments in which horizontal mechanical vibrations and vertical acoustic oscillations were applied simultaneously, with a focus on the effects of the vibrations and oscillations on minimum fluidization velocity and agglomerate size.

Experimental Design and Instrumentation

The experiments were performed in a 0.152 m diameter bed, with a sintered porous plate distributor. The upper part of the bed vessel was fabricated from Plexiglas to allow for external viewing of fluidization and bubbling. Room temperature fluidizing air was supplied to the plenum beneath the distributor, and the flow rate was measured using rotameters. Minimum fluidization velocity was determined from bed pressure drop measurements and visual observation of the bed material. In all experiments, settled bed depths were approximately 9 cm.

A loud speaker at the top of the bed vessel was used to create 80 Hz vertical acoustic vibrations, which ranged up to 148 dB at the upper surface of the distributor. The sound was generated by an audio receiver, signal generator, and loudspeaker. Sound pressure levels were sensed by a microphone immersed in the bed just above the distributor and measured by a sound meter.

The fluidized bed was mounted on a platform that could be moved back and forth on a horizontal track. A variable speed motor with an eccentric cam, attached to the base of the bed plenum, was used to move the bed along the track and generate horizontal mechanical vibrations of the bed vessel. Vibration frequency, which ranged up to 9.5 Hz, was measured by a fiber optic probe mounted in the moving reference frame of the bed and amplitude was determined from the eccentricity of the cam. Amplitudes ranged from 1 to 10 mm.

Experiments with two bed materials are described in this paper: Talc and Aerosil, with surface to volume mean diameters of 15.3 and 0.012 microns, respectively. More details on particle properties are given in Table 1.

Table 1: Powder Characteristics

Bed Material	d_{sv} (μm)	ρ_p (kg/m^3)	ρ_{bulk} (kg/m^3)
Aerosil	0.012	2152	119.7
Talc	15.3	2755	1761.8

The non-dimensional accelerations imposed on the bed by the vibrations are given by Z (acoustics) and Γ (mechanical vibrations), where both parameters are expressed as number of g's.

Results

Aerosil

Aerosil 200 W is a hydrophilic fumed silicon dioxide material with a mean particle size (d_{SV}) of 12 nm. It appears as a fluffy, white powder, and because of large interparticle forces it does not fluidize as individual particles, but rather as agglomerates. Without the addition of vibration, superficial air velocities of 5 cm/s were required to fluidize the material.

Horizontal vibrations were added to the bed and the resulting pressure drop curves are shown in Figure 1 for various vibrational accelerations. This figure also shows a test performed with both mechanical and acoustic vibrations. This test produced the lowest U_{mf}, indicating that the combination of acoustics and horizontal vibrations can be effective in reducing U_{mf}.

Tests were then performed to further explore the effects of combining the acoustic and horizontal vibrations. Several tests were systematically performed at five different sound pressure levels, each at six horizontal vibration levels. The tests started at a Sound Pressure Level (SPL) of 148 dB which corresponded to 20.3 g's and a maximum mechanical vibration of 1.35 g's. The SPL was held constant as the mechanical vibration was decreased from the motor's maximum speed to zero. Figure 2 shows the results of U_{mf} for these experiments.

Figure 2 shows that there was a decrease in U_{mf} value for an increase in either SPL or horizontal vibration strength. For this powder, the range in G-forces of the acoustics is larger than that of the mechanical vibration, and as a result the acoustic vibration had a greater effect on fluidization velocity than the horizontal vibrations. As the SPL was varied from 134 to 148 dB, the minimum fluidization velocity decreased from 5 to 1.4 cm/s at zero horizontal acceleration. On the other hand, U_{mf} decreased a maximum of only 1.7 cm/s as the mechanical vibrations were varied at a fixed SPL.

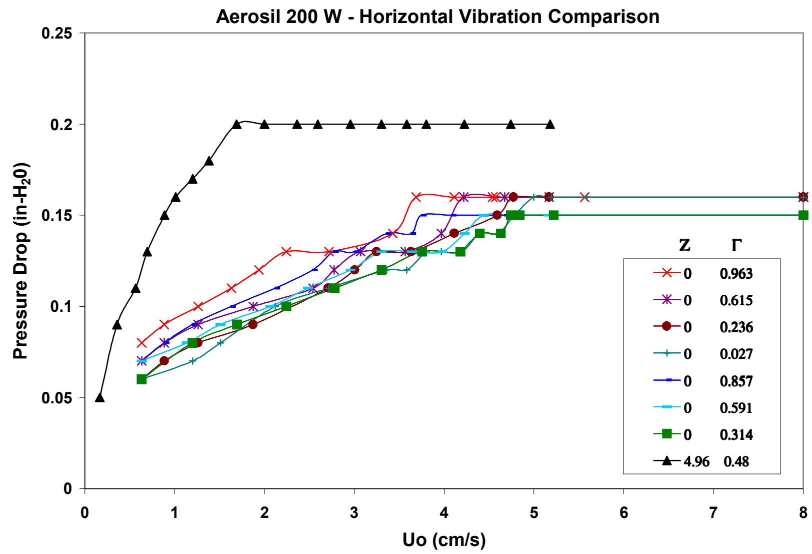

Figure 1: Mechanical Vibrations Added to Fluidization Experiments to Decrease U_{mf} Values

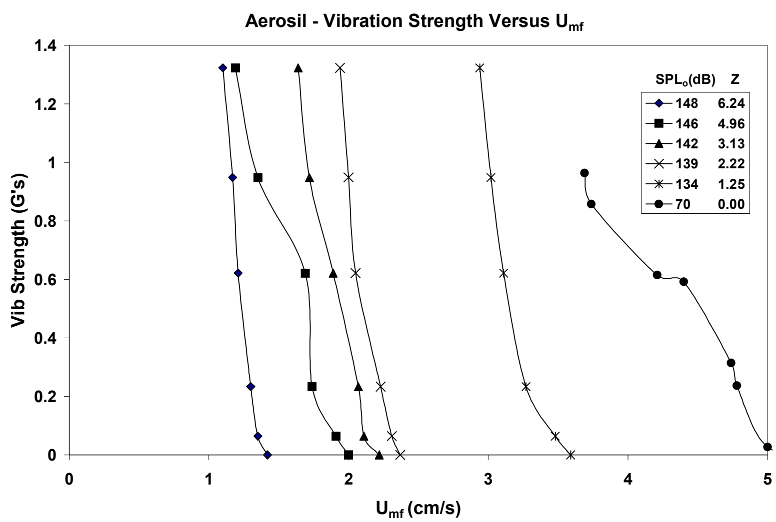

Figure 2: Vibration Strength vs. U_{mf} for Aerosil at Varying Sound Pressure Levels

Vibration strength also affects agglomerate size. Using the equation

$$d_a = \left[\frac{u_{mf}(1-\varepsilon_{mf})\mu}{0.0067 g \varepsilon_{mf}^3 (\rho_a - \rho_f)} \right]^{0.5}$$

agglomerate diameters were determined at varying vibration strengths. Figure 3 shows that at their strongest, the acoustic and mechanical vibrations decreased the agglomerate size by more than 50 percent.

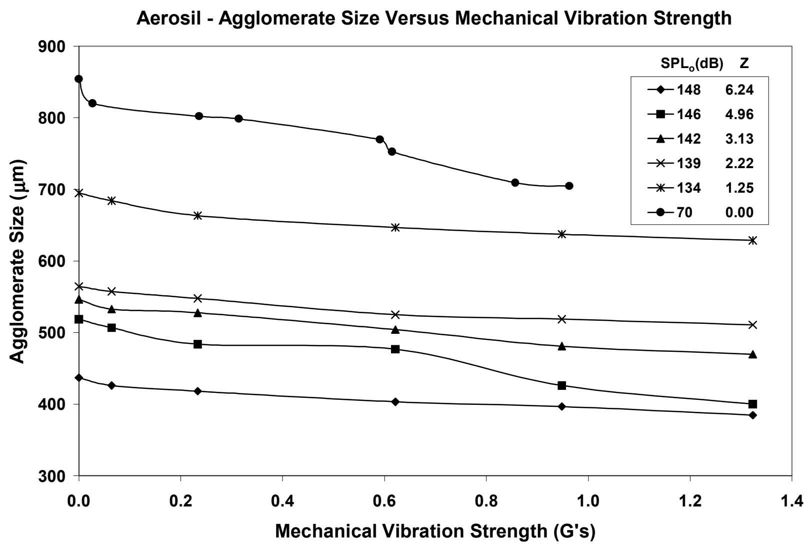

Figure 3: Aerosil Agglomerate Size Versus Mechanical Vibration Strength for Constant Acoustic Vibration Strength

Talc

Talc (Magnesium Silicate Hydroxide), a Geldart Group C powder, was also studied. Talc is normally a very cohesive and sticky powder. It had a relatively high bulk density of 1761.8 kg/m^3 and a mean particle size (d_{SV}) of 15 μm. Talc was able to be fluidized without the addition of mechanical or acoustic vibrations at a velocity around 0.75 cm/s, but visual observation of the bed showed relatively poor mixing. Poor bubbling and some channeling also occurred when fluidized without vibrations.

As vibrations were added, the channels began to break up and the bubbles increased in frequency and size. Better mixing was also present as the particles circulated from the top of the bed to the bottom. Figure 4 shows the effect of the horizontal and acoustic vibrations on U_{mf} and Figure 5 shows the effects of the vibrations on agglomerate size.

Summary and Conclusions

Experiments were performed to determine the relative effects of acoustic and mechanical vibrations on fluidization of fine powders. The acoustic vibrations, which were generated by a loud speaker positioned above the free surface of the bed, caused a vertical vibration of the bed material. The horizontal mechanical vibrations were transmitted by a motor-driven cam to the bed vessel, which, in turn, were transferred to the bed material located next to the vessel wall.

The powders used included normally difficult-to-fluidize talc particles with an average diameter of 15 μm and nanoparticles with a diameter of 0.012 μm. While both powders could be fluidized without the addition of vibrations, the resulting minimum fluidization velocities had magnitudes of 0.75 cm/s for the talc and 5 cm/s for the Aerosil. These relatively large values of U_{mf} are an indication that fluidization occurred with agglomerates of particles rather than with

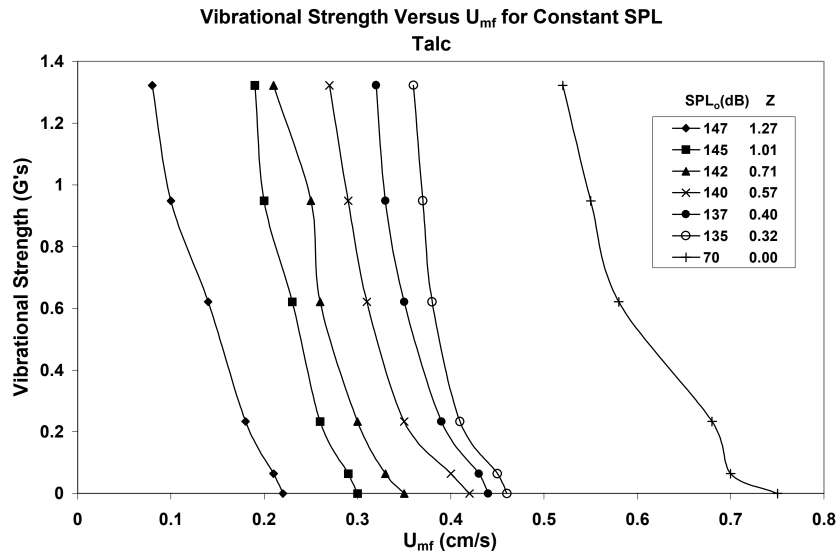

Figure 4: Vibration Strength vs. U_{mf} for Talc at Varying Sound Pressure Levels

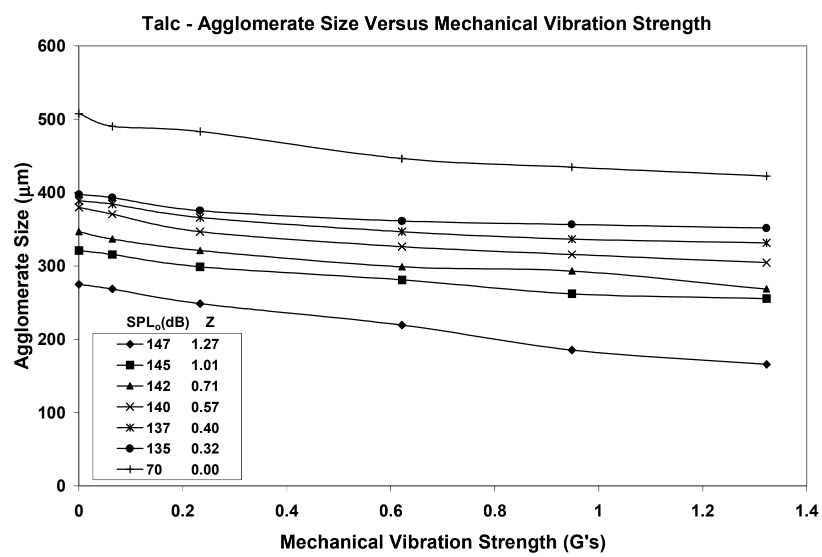

Figure 5: Agglomerate Size for Talc Versus Mechanical Vibration Strength for Constant Acoustic Vibration Strength

individual particles. With the introduction of acoustic and mechanical vibrations, the minimum fluidization velocities were reduced to 1 cm/s (Aerosil) and to less than 0.1 cm/s for the talc. While the data show that both mechanical and acoustic vibrations reduced agglomerate size and U_{mb}, the vertical acoustic vibrations were found to be more effective than the horizontal mechanical vibrations, even when the relative accelerations caused by the mechanical vibrations were of the same magnitude as those caused by the acoustics.