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Minimum fluidization velocity in a 3D fluidized bed modified with an acoustic field

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HIGHLIGHTS

- Minimum fluidization velocity was studied in an acoustic fluidized bed.
- The presence of an acoustic field improved the ease of material fluidization.
- Minimum fluidization velocity is affected by the changes in sound frequency.
- As sound pressure level increased the minimum fluidization decreased.
- Acoustic fluidized beds exhibit dependence between bed height and U_{mf}.

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ABSTRACT

Fluidized beds are used in a variety of process industries because they provide uniform temperature distributions, low pressure drops, and high heat/mass transfer rates. Minimum fluidization velocity is an important factor in understanding the hydrodynamic behavior of fluidized beds, and this characteristic may be modified through high frequency (sound) vibrations. The effects caused by sound wave frequency and sound pressure level on the minimum fluidization velocity in a 3D fluidized bed are investigated in this study. Experiments are carried out in a 10.2 cm ID cold flow fluidized bed filled with either glass beads or ground walnut shell, and particle sizes ranged between 212 and 600 μm. In this study, four different bed height-to-diameter ratios are examined: $H/D = 0.5$, 1, 1.5, and 2. Moreover, the sound frequency of the loudspeaker used as the acoustic source ranged between 50 and 200 Hz, and the sound pressure level ranged 90–120 dB. Results show that the minimum fluidization velocity is influenced by the frequency change. As the frequency increases, the minimum fluidization velocity decreases until a specific frequency is reached, beyond which the minimum fluidization velocity increases. With increasing sound pressure level, the minimum fluidization velocity decreases because the additional vibration forces imparted to the bed particles helps to loosen the bed, reducing the interparticle forces, which reduces the required energy for particle fluidization. Thus, acoustic fields provide an improvement in the ease of fluidization of these particles.

1. Introduction

Characterizing the hydrodynamic behavior of a fluidized bed is very complex and must be understood better in order to improve fluidized bed operations. Minimum fluidization velocity is one of the most important parameters when characterizing the hydrodynamics in a fluidized bed [1]. The minimum fluidization velocity (U_{mf}) is the superficial gas velocity at which solid particles are just suspended in the fluidizing medium. The minimum fluidization velocity depends on the material properties, bed geometry, and fluid properties. Sau et al. [2] determined the minimum fluidization velocity for a gas–solid system in a tapered fluidized bed for different Geldart Type B particles and studied the effects that bed geometry, specifically the tapered angle, had on the minimum fluidization velocity. Results showed U_{mf} changed when the geometry of the bed changed.

Moreover, Hilal et al. [3] analyzed the effects of bed diameter, gas distributor, and inserts on minimum fluidization velocity for particles of different diameter and density. It was shown that both the bed diameter and the type and geometry of the distributor affected U_{mf}. For example, U_{mf} increased with an increase in the number of holes in the distributor plate. Furthermore, with an increase in the bed diameter, there was a decrease in U_{mf}. Finally, the insertion of tubes along the fluidized bed reduced the effective cross-sectional area for fluidization, which produced a higher interstitial gas velocity causing a decrease in U_{mf}.

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The influence of bed height on minimum fluidization velocity has been studied using different types of fluidized beds. Zhong et al. [4] completed minimum fluidization experiments in spouted fluidized beds. In a spouted fluidized bed, the bed chamber is tapered like a funnel, which creates different hydrodynamics, and the fluidization air is typically injected through a single orifice. Filling the bed with different materials (Geldart type D) to different heights (300–550 mm), they determined that the minimum spouting fluidization velocity, which is analogous to the minimum fluidization velocity in a bubbling fluidized bed, was influenced by the change in bed height; increasing the bed height increased the spouting velocity.

Sau et al. [2] used a gas–solid conical tapered fluidized bed to find the minimum fluidization velocity and the pressure drop across the bed. They concluded that bed height for this type of bed did not have a significant effect on the minimum fluidization velocity, i.e., U_{mf} was independent of bed height for this type of conical tapered fluidized bed.

Ramos Caicedo et al. [1] studied the minimum fluidization velocity for gas–solid 2D fluidized beds for Geldart type B glass beads. Their results revealed that as the static bed height increased, U_{mf} increased.

Gunn and Hilal [5] and Cranfield and Geldart [6] studied gas–solid 3D fluidized beds using glass beads (Geldart type B particle) as the bed material and four different bed heights. The results for minimum fluidization velocity in both studies showed that for all the material and experimental conditions used, there was no significant change in the minimum fluidization velocity when the bed height was increased. Therefore, U_{mf} was independent of bed height. Similar results showing independence between minimum fluidization velocity and bed height were concluded by Escudero and Heindel [7] using different Geldart type B particles (glass beads, ground walnut shell, and ground corncob) in the size range of 500–600 μm.

Mechanical vibrations are being used to ease fluidization in materials that present poor fluidization quality. Zhang et al. [8] studied the fluidization characteristics of fly ash in a fluidized bed subjected to mechanical vibrations. They found that the minimum fluidization velocity decreased due to the vibrations, implying that fly ash can be fluidized at a lower superficial gas velocity. Marring et al. [9] studied the effect of vibration on the fluidization behavior of glass beads and potato starch. Using Geldart type A particles, they found that increasing the frequency and the amplitude of the vibrations decreased the minimum fluidization velocity and the bed voidage. Moreover, for a more cohesive powder like potato starch, which presents a poor fluidization quality without vibration, the use of vibration allowed the bed to fluidize well even with different levels of cohesiveness, thus showing vibration improved the fluidization of cohesive powders.

Barletta et al. [10] also studied the effects of mechanical vibration on the fluidization of a fine aeratable FCC powder. Changing the parameters of peak acceleration and frequency, they determined the effects on bed expansion, voidage, and fluidization. They found that the degree of static (no air flow) bed packing reached by the vibrated bed was always higher than that reached without vibration. Also, the pressure drop in the fully fluidized bed may be equal to or smaller than (sometimes significantly) those obtained without vibration. The bed started to expand when the gas pressure drop was consistently smaller than what was necessary for fluidization. The largest bed expansion of the vibrated bed was always smaller than that attained without vibration. If the discrepancies between vibrated and not vibrated fluidization was assumed as a measure of the significance of the effect of vibration, these were generally larger at low frequencies and tended to become less important at high frequencies; these effects were also apparent under full fluidization conditions. More recent studies were performed by Barletta and Poletto [11] and Barletta et al. [12] to analyze the effects of mechanical vibrations on the dynamic response of fine and cohesive powders.

Sound-assisted fluidized beds have been studied for different Geldart type particles (Geldart type A–C) to understand the effects produced by the acoustic field on the fluidization behavior and quality [13–15]. This is an attractive option because it is a noninvasive technique that could influence the bed hydrodynamic structure without affecting the properties of the bed material.

Leu et al. [16] studied the fluidization of Geldart type B particles in an acoustic fluidized bed. They determined the influence of the speaker power, sound frequency, particle loading, and distance between the speaker and bed surface on the hydrodynamic properties of a fluidized bed filled with 194 μm sand. They found that when an acoustic field was applied, a different particle loading height created a different minimum fluidization velocity, making minimum fluidization velocity dependent on bed height. Guo et al. [17] investigated the behavior of ultrafine (Geldart type C) particles under the influence of sound waves. They studied both nanometer and micrometer size particles. They found that as frequency increased, the minimum fluidization velocity decreased and then after a specified frequency (40–50 Hz), the minimum fluidization velocity increased. When the sound pressure level was changed (100–103.4 dB) and the sound frequency fixed, the minimum fluidization velocity decreased for all particles, thus improving the fluidization quality of the particles. The same trends were found by Kaliyaperumal et al. [18] and Levy et al. [19].

Moreover, Guo et al. [20] analyzed the effects of the acoustic field on a fluidized bed at different temperatures for quartz sand (74 μm, 2650 kg/m^3) and SiO_2 particles (0.5 μm, 2560 kg/m^3). The results obtained in that study showed that minimum fluidization velocity decreased with increasing temperature with, as well as without, acoustic assistance. In the same way, at a fixed sound pressure level (120 dB), the minimum fluidization velocity decreased when the frequency was increased from 50 to 200 Hz, and then the minimum fluidization velocity increased with frequency from 200 to 400 Hz.

Si and Guo [21] studied how an acoustic fluidized bed improved the fluidization of two different biomass particles, sawdust and wheat stalks, alone or mixed with quartz sand. They compared the fluidization behavior of the biomass without and with the acoustic field to determine if there was any improvement due to the acoustic field. They also determined the influence of sound pressure level (SPL) on the minimum fluidization velocity. Initially, they found that the biomass by itself fluidized poorly with and without the presence of the acoustic field. They then added quartz sand to aid fluidization and maintained the biomass mass fraction at 60%. They observed that below a SPL of 90 dB, plugging and channeling occurred in the fluidized bed. Increasing the SPL diminished the effects of channeling and improved the fluidization quality. By varying the sound frequency between 50 and 400 Hz, they determined that the minimum fluidization velocity decreased with increasing frequency until it reached a minimum value and then increased with increasing frequency.

Si and Guo [21] also fixed the sound frequency at 150 Hz and varied the sound pressure level between 90 and 120 dB. Using these conditions, they determined the effects on the minimum fluidization velocity. They found that when the sound pressure level was above 100 dB, the fluidization quality improved, and they observed that the biomass mixture fluidized smoothly without any obvious slugging or channeling.

The goal of this paper is to determine the effects caused by an acoustic field on the minimum fluidization velocity of Geldart type B particles in a 3D cylindrical fluidized bed filled to different bed heights.