

THE INFLUENCE OF ACOUSTIC FIELD AND FREQUENCY ON HYDRODYNAMICS OF GROUP B PARTICLES

by

Akash M. LANGDE^{a*}, **Ram L. SONOLIKAR**^b, and **Dharmaraj J. TIDKE**^c

^a Mechanical Engineering Department, Anjuman College of Engineering and Technology,
Nagpur, India

^b Department Chemical Engineering, Laxminarayan Institute of Technology, Nagpur, India

^c Acharya Vinoba Bhave Institute of Technology, Wardha, Maharashtra, India

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Sound assisted fluidized bed of group B particles (180 μm glass bead) has been studied in a 46 mm I. D. column with aspect ratios of 1.4 and 2.9. A loudspeaker mounted on the top of the bed was supplied by a function generator with square wave to generate the sound as the source of vibration of the fluidized bed. The sound pressure level (referred to 20 Pa) was varied from 102 to 140 dB and frequencies from 70 Hz to 170 Hz were applied. The effects of sound pressure level, sound frequency, and particle loading on the properties of sound assisted fluidized bed were investigated.

The experimental result showed that the minimum fluidization velocity decreased with the increase in sound pressure level, also minimum fluidization velocity was varied with variation of frequencies. At resonance frequency minimum fluidization velocity was found to be minimum. The bed height did not show an appreciable increase in presence of high acoustic field and at resonant frequency. Minimum fluidization velocity vs. frequency curve in presence of sound intensity varied with variation of bed weight.

Key words: minimum fluidization velocity, acoustic, frequency, vibration, aspect ratio, group B

Introduction

Recent interest in processing of fine particles raises the practical question of the fluidizability of non-fluent solids. For number of applications, particularly in ceramic processing, it is often desired to obtain powder flowability without agglomerates. However, fluidization of very fine, cohesive powders (less than 75 μm) is difficult to fluidize, since they have very poor flow characteristics. Moreover, gas channels and stagnant zones are formed in the bed resulting in restricted particle motion. Once the channels have been created, they tend to enlarge with further increase in gas velocity. In recent years, the use of additional forces (*i. e.* mechanical vibration, stirring elements, *etc.*) has been tested to improve the quality of fluidization of cohesive powders. However; much of attention has been directed towards vibrated bed.

* Corresponding author; e-mail: akashlangde@gmail.com

The pioneering work was done by Morse [1], who studied the effect of sound on a fluidized bed. During experimentation, the loudspeaker was kept at the bottom of the bed. Sonic energy of sufficient intensity (above 110 dB) of low frequency (from 50 to 500 Hz) would cause non-fluent group C particles to flow well, so that good fluidization is possible without channeling and stagnation.

Nowak *et al.* [2] formulated the correlation for minimum fluidization velocity with assistance of sound and used the source of sound at the top as well as bottom of the unit. The measurement was done at different frequencies and decrease in minimum fluidization velocity occurred at 97, 157, and 894 Hz. The heat transfer characteristic of non-fluent solid improved due to low acoustic frequency.

Chirone *et al.* [3] developed the cluster/subcluster oscillator model based on the assumption that the cluster is stationary in the space under the effect of cohesive van der Waals forces, which stick to each other and forms large aggregates. As a consequence, the bed has been modeled as structured in clusters that can break up into subclusters, due to the acoustic field.

Chirone *et al.* [4] studied the effect of acoustic field on different cohesive solids, ranging from 0.3 to 11 μm up to SPL of 150 dB. It was seen that, when observed under electron microscope the solid showed different particle surface geometries. Sound-assisted aeration gives rise to bubble free fluidization. The use of word aeration instead of fluidization reflects the fact that in spite of the presence of an acoustic field, the gas did not flow homogeneously through the bed. A correlation was obtained for bed expansion and fluidizing curve. Sound – assisted aeration gave rise to bubble free fluidization only in case of catalyst, ash, and talc.

Levy *et al.* [5] determined the characteristics of acoustic standing waves in fluidized beds. Sound pressure measurements within the bed showed the presence of acoustic standing waves throughout the bed. According to assumption of acoustic standing wave theory, the bed behaves as a 1-D, quasi fluid. It was found that the parameter kh , where k is the wave number and h is the bed depth, determines the sound pressure amplitude throughout the bed.

Russo *et al.* [6] investigated the effects of bed weight and intensity of the acoustic field (from no sound to sound pressure level – SPL, at 140 dB). The frequency was maintained at the constant frequency 120 Hz in all the experiments. The results of the experiment showed, for a certain bed weight, an acoustic field of appropriate SPL changes the channeling typically observed with group C cohesive powders into the homogeneous bubble free bed.

In his latter studies, Levy *et al.* [7] observed the effect of sound, promoting more uniform fluidization and bed expansion. In this study, they found the combined effects of gas velocity, frequency, and intensity of sound waves on bubble dynamics by using fiber optic probe.

Xu *et al.* [8] reported that, fluidization quality of fine particles can be enhanced with the assistance of a sound field. Application of sound field results, in higher pressure drops and lower minimum fluidization velocity. In his study, a novel application of an acoustic field was attempted experimentally to identify Geldart groups C and A particles. It is then further stated that, in terms of the different attenuation features of sonic waves in the gas solid suspension of groups C and A particles, sound field is for the first time used to distinguish group C particles from group A particles.

Levy *et al.* [9] reported the effect of sound intensity on gas-fluidized bed for separation of the bed materials into low and high-density component. The experimental results, performed with fine fly ash particles showed the strong effect.

Guo *et al.* [10] investigated the fluidization behaviors of ultrafine particles in an acoustic fluidized bed with one type of micron particles and two types of nanoparticles ($d_p = 500 \text{ nm} - 10.69 \mu\text{m}$).

It was stated that, with the assistance of sound wave with low sound frequency and high sound pressure level, the micron and nanoparticles can be fluidized smoothly with fluidization behaviors similar to those of Geldart group A particles. It has been found that increasing sound frequency leads to a reduction in minimum fluidization velocity upto certain frequency, and then to increases. At the same sound frequency, the fluidization quality of nanoparticles improves significantly with increasing sound pressure level (100-103.4 dB). In addition, experiments shows that both sine wave and triangular wave can enhance fluidization quality of ultra fine particles.

Leu *et al.* [11] studied the behavior of eight different types of Geldart group C particles in the sound vibrated fluidized bed and estimated the interparticle force.

Levy *et al.* [12] studied the combined effects of mechanical and acoustic vibrations on fluidization of cohesive power. With the introduction of acoustic and mechanical vibrations, both the minimum fluidization velocity and agglomerate size got reduced. They came to the conclusion that, acoustic vibrations were more effective compared to mechanical vibration.

Xu *et al.* [13] investigated the effects of vibration on fluidization of fine particles (4.8-216 μm average in size) show that the fluidization quality of fine particles can be enhanced under mechanical vibration, leading to larger bed pressure drops at low superficial gas velocities and lower values of U_{mf} .

Leu and Chen [14] extended his work for group B particles by putting the source at the top of bed to investigate the primary effect of acoustic field on the fluidization. It was observed that the minimum fluidization velocity decreases with sound intensity.

Leu *et al.* [15] investigated the influence of sound intensity on following parameters: minimum fluidization velocity, standard deviation of pressure fluctuations, and bubble rise velocity on group B particle.

Zhu *et al.* [16] studied the effect of acoustic field on nanoparticles and found that minimum fluidization velocity decreased with increase in sound intensity at low frequency.

Looking to above literature much of attention was given to fluidization of fine cohesive powder. Little work has been done on group B particles in presence of an acoustic field. Though group B particles easily flowable but authors aimed towards to improve the efficiency of process. Hence, the present work has been directed towards investigating how, the sound pressure level, the acoustic frequency and the L/D ratio influence the minimum fluidization velocity of group B particles.

Experimental

The experimental set up is shown in fig. 1. It consists of fluidization column and sound generation system. The column made of plexiglas has an inner diameter of 46 mm and 400 mm height. A porous distributor was located at the bottom of the column. Experiments were performed with air at atmospheric pressure and room temperature. The air flow rate was measured by using rotameter. The pressure drop ΔP was measured across the bed. A digital signal generator was used to obtain square wave of specified frequency. The signal was amplified by means of a power audio amplifier and sent to a 4", 15 cm diameter speaker of 25 watt with its working frequency in the range from 20 Hz to 20 kHz. The speaker was placed at the top of the column. Sound pressure were picked up by a 1/4 inch Brüel & Kjær condenser microphone of type 4944 A and recorded on a digital Tektronix oscilloscope (TDS210). The stored

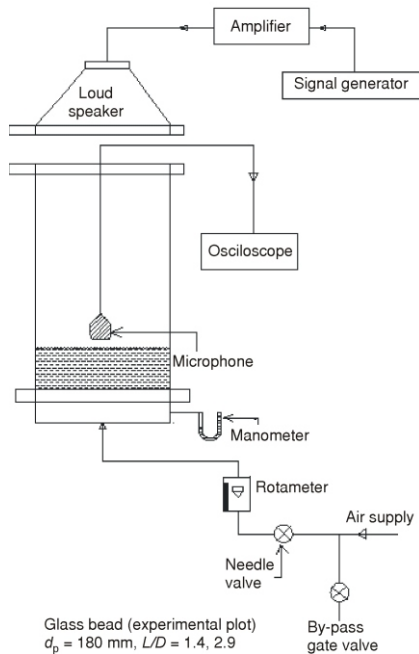


Figure 1. Experimental set-up

signals were worked out to obtain the SPL. Experiments were carried out by keeping the microphone 5 cm above the bed surface.

A glass bead of 180 μm mean particle diameter with size range of 150-210 μm and particle density 2600 kg/m^3 were used as a fluidizing material. Experiments were carried out at a sound pressure level up to 140 dB. The details of operating conditions were shown in tab. 1.

Table 1. Operating conditions

Fluidizing gas	Air
Fluidizing gas velocity, U_o [cm s^{-1}]	up to 10
Bed weight W , [kg]	0.16 and 0.32
Aspect ratio, $[L/D]$	1.4 and 2.9
Acoustic field frequency, f [Hz]	70-170
Sound pressure level above the bed, [dB]	108-140

Results and discussion

Effect of sound intensity on minimum fluidization velocity

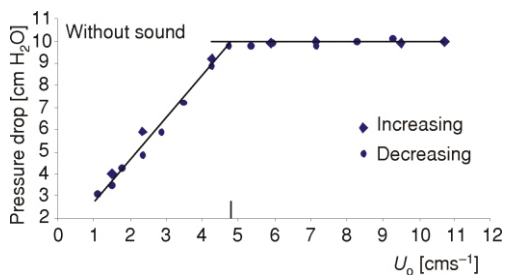


Figure 2. Variation of pressure drop with gas velocity in absence of sound intensity

Figure 2 showed the variation of pressure drop vs. gas velocity without sound intensity. Fluidization curves for $L/D = 1.4$ and 2.9 , activated by acoustic field of different sound intensities (102-140 dB) and frequencies (90-170 Hz) are shown in figs. 3 and 4. The ordinates of the diagrams are expressed as pressure drop ΔP across the bed and abscissa is the superficial gas velocity, U_o . Experiments were conducted with fluidization and defluidization process. From figs. 2-4 it could be seen that the minimum fluidization velocity U_{mfs} , decreased due to presence of sound intensity and ranged from 4.8

cm/s to 3.2 cm/s from no sound condition to sound at 140 dB and 120 Hz for $L/D = 1.4$. It was also observed that the U_{mfs} did not reduce appreciably compared to group C particle [6].

The result, plotted in fig. 5, is the pressure drop across the bed. This pressure drop was decreased due to assistance of acoustic field compared to without sound intensity.

Figure 6 depicted the variation of minimum fluidization velocity (U_{mfs}) with sound intensity keeping frequency constant from 70 to 170 Hz for both L/D ratios. It can be noticed that,

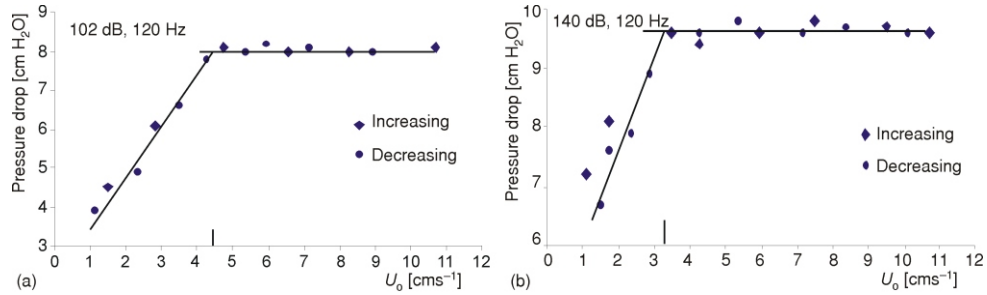


Figure 3(a) and (b). Variation of pressure drop with gas velocity when sound intensity applied at 102 dB, 140 dB, and 120 Hz frequency at $L/D = 1.4$

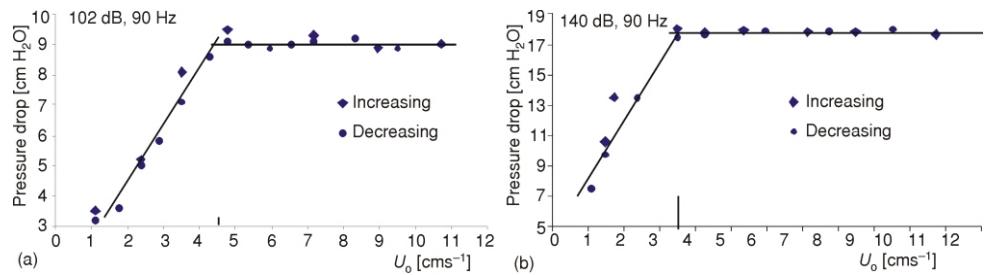


Figure 4(a) and (b). Variation of pressure drop with gas velocity when sound intensity applied at 102 dB, 140 dB, and 90 Hz frequency at $L/D = 2.9$

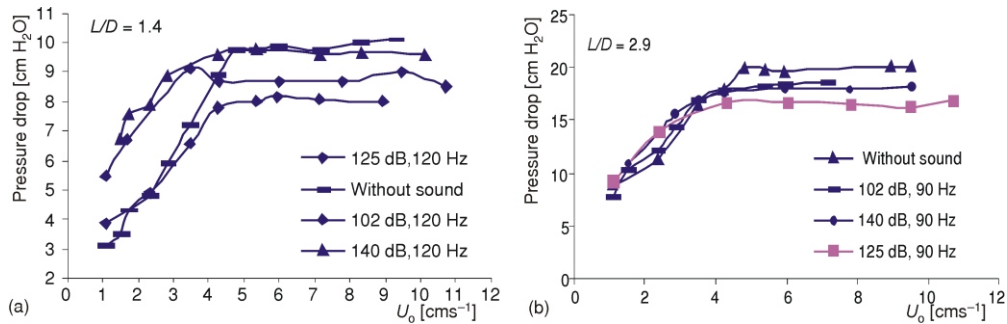


Figure 5(a) and (b). Variation of pressure drop with gas velocity when $L/D = 1.4$ and 2.9 , respectively

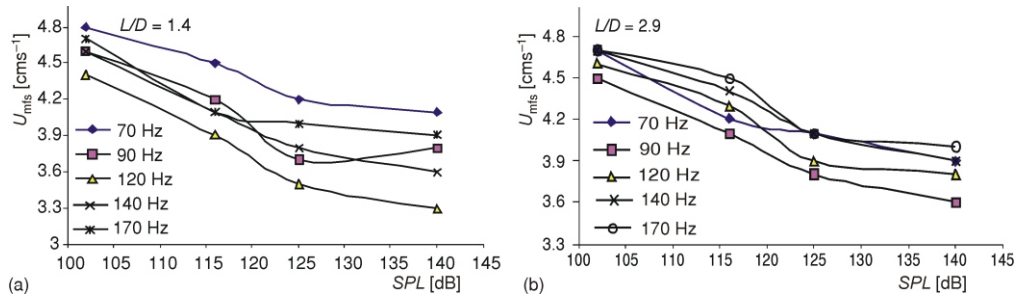


Figure 6(a) and (b). Variation of U_{mfs} with sound pressure level

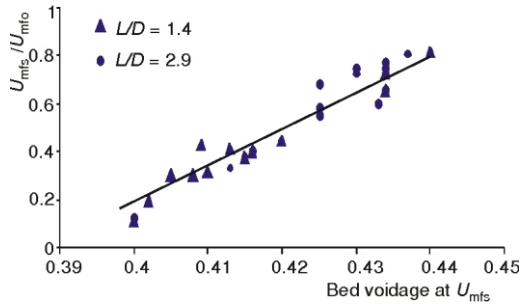


Figure 7. Variation of minimum fluidization velocity ratio to bed voidage

increase in sound intensity showed a decrease in U_{mfs} upto 125 dB. Marginally decrease in U_{mfs} observed after 125 dB and remains more or less constant. The similar type of work has been reported by Leu *et al.* [11], referred the effect of power of the sound. Figure 7 depicted the relationship between minimum fluidization velocity ratio with sound intensity and bed voidage at minimum fluidization condition. It was found that the data for different frequencies, sound pressure levels, and bed heights were well correlated by a straight line, and it could be represented by the equation:

$$3.58\varepsilon_{mfs}U_{mfo} - 1.1U_{mfo} - U_{mfs} = 0 \quad (1)$$

From eq. (1) it was noted that bed voidage reduces in presence of acoustic field.

Effect of frequency on minimum fluidization velocity in presence of sound

The effect of frequency on U_{mf} in presence of sound was investigated, as it was a key parameter which can change the quality of fluidization. From fig. 8(a) for $L/D = 1.4$, it was observed that, the sound intensity at 120 Hz had the maximum effect on minimum fluidization velocity, because 120 Hz was the resonant frequency for this bed height. From fig. 8(b) for $L/D = 2.9$, 90 Hz frequency had the maximum effect on minimum fluidization velocity, because 90 Hz was the reso-

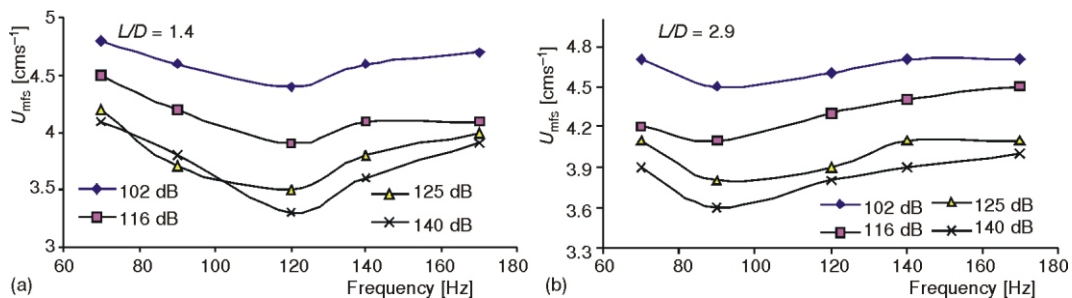


Figure 8(a) and (b). Variation of U_{mfs} with acoustic frequency

nant frequency for this bed height. Figure 8 depicts the values of minimum fluidization velocity for L/D ratios of 1.4 and 2.9 and frequency from 70 Hz to 170 Hz at constant sound intensity. The minimum fluidization velocity was first decreases with increasing frequency then increases. This is due to the effect of an acoustic frequency, which gives dynamic effect on the particles with change in frequency. The minima was obtained at resonance frequency of the column. This result is slightly different from Chirone *et al.* [6] for group C particle; they found minima at constant frequency regardless amount of solid in the bed.

Effect of L/D ratio on minimum fluidization velocity

Figure 9 depicts the variation of U_{mfs} with frequency for different L/D ratio at constant sound intensity. It was observed that, U_{mfs} increases at resonance with increase in L/D ratio for all frequencies except for 70 Hz and 90 Hz for $L/D = 1.4$. The possible reason is that, increase in the sound attenuation due to the larger amount of solids, decreases the SPL under which beds of different L/D are operated. The minima observed at 120 Hz and 90 Hz for L/D ratio of 1.4 and 2.9, respectively. Figure 9 also represents, regardless the value of L/D , the trend of variation of U_{mfs} with the frequency is the same as reported in fig. 9.

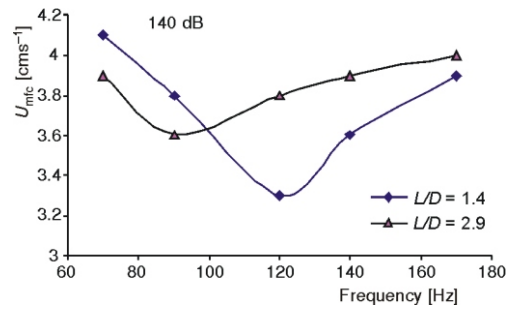


Figure 9. Variation of U_{mfs} with acoustic frequency [Hz]

Effect of sound pressure level on bed expansion

Figure 10 deduced the bed expansion during fluidization and defluidization process for different L/D ratios for with and without sound intensity at 140 dB. The expansion of bed at 140 dB was observed more compared to without assistance of acoustic field. This implicates that positive response of acoustic field towards group B particle. It could also be compared that bed expansion was small compared to group C particle when exposed to acoustic field. Also it was observed that, the bed collapses very rapidly when the gas supply was cut off compared to group C particle in presence of acoustic field.

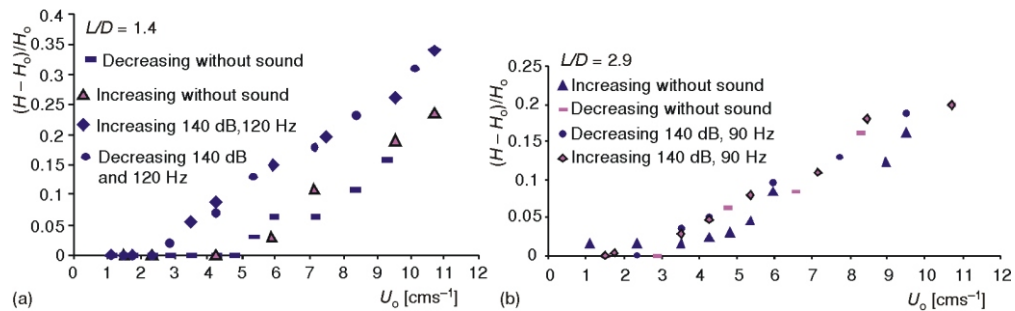


Figure 10. Variation of bed expansion with gas velocity when without sound and with sound intensity at 140 dB for $L/D = 1.4$ (a) and 2.9 (b)

Effect of sound on minimum bubbling velocity

From the visual observation of the bed surface for these particles, it was observed that, once the minimum fluidization velocity is exceeded, the excess gas appears in the form of bubbles. Bubbles in a bed of group B particles can grow to a large size but it was observed that bub-

ble size reduced in presence of acoustic field. In contrast with group A powders, naturally occurring bubbles start to form in this type of powder at or only slightly above minimum fluidization velocity. There is little or no powder circulation in the absence of bubbles and bubbles burst at the surface of the bed as discrete entities. When the gas velocity is so high that slugging commences, the slugs are initially axi-symmetric, but with further increase in gas velocity an increasing proportion become asymmetric but this process of asymmetric get delay due to presence of acoustic field, moving up the bed wall with an enhanced velocity rather than up the tube axis. There is no evidence of the breakdown of slugging into turbulent flow.

Figure 11 depicts the variation of minimum bubbling velocity (U_{mbs}) with acoustic intensity at constant frequency *i. e.* 120 Hz for both L/D ratios. It was noticed that, from 108 to 125 dB U_{mbs} was constant; equal to 4.3 cm/s. As the particles belong to B group, sound intensity from 108 to 125 dB did not helped too much in fluidization process. Hence U_{mbs} was constant for all these sound level values. There is a distinct change in slope from 125 dB to 140 dB, which shows change in effect of the sound waves on the bubbling properties of the bed material. Levy *et al.* [7] reported the continuous decrease in U_{mbs} at all range of sound intensity.

Variation of U_{mbs} vs. frequency at constant sound intensity *i. e.* at 140 dB reported in fig. 12. Experimental data shows the values of U_{mbs} remain constant for all range of frequencies *i. e.* from 70 Hz to 170 Hz except 120 Hz for $L/D = 1.4$ and 90 Hz for $L/D = 2.9$. This was due to maximum response of column to the resonance frequency. Levy *et al.* [7] presented the trend of U_{mbs} , *i. e.* first decreases and then increases at constant *SPL*.

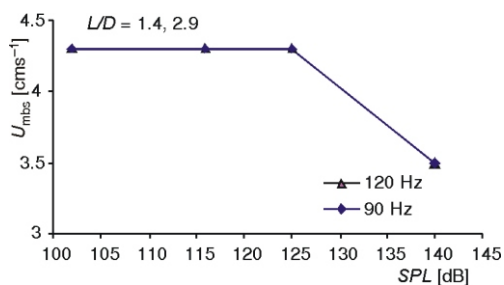


Figure 11. Variation of U_{mbs} with sound pressure level at constant frequency

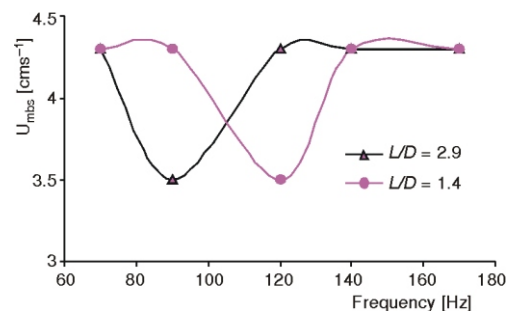


Figure 12. Variation of U_{mbs} with acoustic frequencies

Conclusions

Experiment was performed with group B particles having a mean diameter of approximately 180 μm , using room temperature air as the fluidizing gas. The operation was carried out with approximate combination of acoustic field intensity, frequency, and L/D ratio. As sound intensity increases U_{mfs} decreases from 108 dB to 140 dB. A useful range of frequencies ranging between 70 Hz and 170 Hz was found when different L/D ratios are operated with acoustic field. The maximum effect of sound intensity on U_{mf} was observed at 120 Hz and 90 Hz for L/D ratio 1.4 and 2.9, respectively. It was also seen that, U_{mfs} decreases with increase in frequency and then increases. The minimum fluidization velocity increases with increasing L/D ratio. In addition, it was noticed that, effect of acoustic field on bed height of the group B particle was not so appreciable. The value of U_{mbs} decreases in presence of sound pressure level.

Appendix

Sound pressure is commonly expressed in acoustic terminology as the product of 20 times the logarithm (base 10) of the ratio of sound pressure to a specified reference sound pressure. The standard reference sound pressure is $20 \cdot 10^{-6}$ Pa.

This relationship is expressed by:

$$SPL = 20 \log \frac{P}{P_0} \quad (2)$$

Nomenclature

f	– frequency of sound, [Hz]	U_{mf}, U_{mfo}	– minimum fluidization velocity without sound intensity, [cms^{-1}]
H	– expanded bed height [cm]	U_{mbs}	– minimum bubbling velocity with sound intensity, [cms^{-1}]
H_0	– static bed height, [cm]	U_o	– superficial gas velocity, [cms^{-1}]
P	– sound pressure measured root mean square, [Pa]	L	– static bed height, [m]
P_0	– reference pressure, [Pa]	D	– internal diameter of fluidized bed, [m]
ΔP	– pressure drop across the bed cm of water	L/D	– aspect ratio, [–]
SPL	– sound pressure level, [dB]	ε_{mfs}	– bed voidage at minimum fluidization velocity
U_{mfs}	– minimum fluidization velocity with sound intensity, [cms^{-1}]		

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