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Experimental investigation of minimum fluidization velocity of micron size particles in presence of an acoustic field

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ABSTRACT: *The fluidization behavior of silica gel was tested in a fluidized bed under different sound pressure levels and sound frequencies. It has been found that the particle mixtures can be fluidized smoothly with sound assistance at low sound frequency owing to the sound energy disrupting large size of agglomerates. The minimum fluidization velocity was found to decrease with increasing sound frequency. It then increases at the same sound pressure level. At a given sound frequency minimum fluidization velocity reduces substantially with the increase in sound pressure level. Bed expansion was observed in presence of sound intensity.*

Keywords: *fine powder; cohesive; sound frequency; minimum fluidization velocity.*

I. INTRODUCTION

Modern industrial production methods seek process environments that minimize harmful damage to the environment. In many instances, industries strive to develop new processes aimed at reducing waste generation and making more efficient use of resources. Specific processes have been developed for efficient utilization of natural resources for producing different products. Among the best known and widely used processes in modern manufacturing is fluidized bed technology.

Gas solid fluidized beds have been extensively used in industries, such as for coating and granulation, due to easy handling of materials and rapid heat and mass transfer rate. Despite of several advantages, a few basic and inherent drawbacks, such as channeling, bubbling and slugging, have made wide spread use of this technology rather difficult. Cohesiveness of materials is one of important factors that adversely affect the fluidization quality. To overcome the problems associated fluidization of fine powder, several investigators have used in the recent years a variety of technologies and scientific principles, including application of additional force. Different methods to achieve homogeneous fluidization include vertical vibration by means of mechanical devices (Xu *et al.* 2006) and acoustic field concurrent to fluidizing gas (Morse 1955, Nowak *et al.* 1993) etc. All these improvements in fluidization parameters are related to minimum fluidization velocity. Application of acoustic field for fluidization of fine powder showed good effect with homogeneous fluidization. It is very easy to operate and consumes less power. Morse (1955) pioneered the application of sonic energy in fluidized bed and found that improvement in quality of fluidization is significant at low frequency. Nowak et al. (1993) reported data on the effect of sound wave on minimum fluidization velocity, bed expansion and heat transfer rate in fluidized bed. In his study, various materials were used ranging from 7 to 97 μm in size and sound pressure level (SPL) greater than 100 dB. The study showed good effect on the quality of fluidization. In addition, a correlation was developed for minimum fluidization velocity without sound. Extensive work was done by Chirone and co-workers (1995). They formulated the cluster - subcluster oscillator model with the assumption that the cluster is stationary in the space under the effect of cohesive van der Waals forces and stick to each other forming large aggregates. Therefore, the bed was modeled as structure in clusters that can break up into sub clusters due to the acoustic field. They also published data on variation of frequency on minimum fluidization velocity and bed expansion. Most of the experiments were performed at 120 Hz with sound pressure level ranges from 110 to 150 dB. Levy and coworkers (1997, 2006) reported their data on bubble dynamics, acoustic standing wave, and separation of material from fly ash based on density difference. The comparison of mechanical vibrating system with acoustic system and its combined effect were also investigated within the range of frequency 90 Hz to 300 Hz and sound pressure level from 100 to 150 dB. Leu and coworkers (1994, 1997) worked on group B and C particles individually. Sand was used as group B particle with mean particle diameter 194 μm. They found that minimum fluidization velocity decreases with increase in sound intensity. In addition, seven materials were used as group C particles in fluidization with the assistance of acoustic field. It was also mentioned that some material does not respond to the acoustic field despite of low frequency and high intensity. Langde et.al (2011) worked on two different particles, 112 μm micro fumed silica and 180 μm glass bead powders, and reported that these two particle types gave good quality of fluidization in presence of acoustic field when compared with the performance without any sound field.

II. EXPERIMENTAL SET UP

The apparatus used for the present investigation is shown in Fig.1. It consists of a fluidization column and sound generation system. The column made of cylindrical clear Plexiglas has an inner diameter of 135 mm and height 500 mm. Experiments were performed at room temperature and atmospheric conditions. The fluidization gas was air which was obtained from an air compressor. The compressor has capacity to deliver the air up to 8 bar. A porous distributor located at the very bottom of the column, distributes air uniformly into the bed. A gate valve was provided to maintain uniform inlet rotameter pressure. Eureka^{TM} rotameter of uncertainty 3% of the full-scale reading was used to measure gas flow rate. Water manometer was used to measure the pressure drop across the distributor and bed. A millimeter ruler tape was attached to the column, to measure the movement of bed material and microphone shown in Fig 1. 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 20x10^{-6} pa. Sound pressure level (SPL) in dB is expressed as

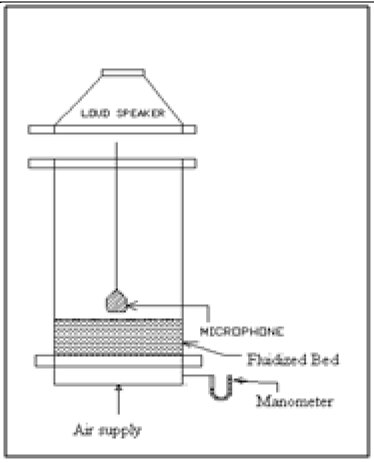

Fig. 1: Experimental setup

$$SPL = 20 \log_{10} \quad P_{rms} \; / \; P_{ref}$$

Where P_{rms} is sound pressure measured as root mean square quantity (pa) and P_{ref} is the reference pressure (pa). The sound source includes a sound amplifier, a function signal generator and a loud speaker. A Bolton^{TM} loudspeaker model, 196 mm in diameter, 4 Ω rated at 40 w with an audible range frequency of 20Hz – 20 kHz was used. The speaker was located at the top of the bed to generate sound as source of acoustic field. It was powered with a Mega^{TM} amplifier; model 35 Ab 4, and was able to deliver 50 W output per channel. Output of loudspeaker was controlled by amplifier through volume knob. A Testronix^{TM} model- 59 function signal generator was used to produce different types of electric pulse waves. To find out best effect of pulse wave on the fluidize bed, the bed was first tested with different pulse waves before starting the experiments. The different types of pulse waves used are - triangular, square, sine and cosine waves. It has been seen that the sine wave has the strongest effect on the particles. During experimentation, sound frequency was controlled by simply selecting the function generator. The sound pressure level measuring system includes a microphone attached to a movable bar tip. The microphone was Brüel & Kjǽr^{TM} condenser type model 4944 (see Fig.1). Deltotran make power supply, with uncertainty of 95%, confidence level 0.3 dB and 170 dB maximum was used. One end of the microphone was attached to the oscilloscope Tektronix^{TM} model TdS-210. This was used to measure sound pressure level. The microphone was covered with filter cloth to prevent fine particles to reach up to the diaphragm when immersed in the bed.

Table 1: Operating conditions

Fluidizing gas
Fluidizing / Superficial gas velocity, U_o (cm/s)
Bed weight W, (kg)
Acoustic field frequency, f (Hz)
Sound pressure level above the bed, (dB)

III. RESULTS AND DISCUSSION:

3.1 Fluidization in absence of sound intensity:

The material was tested with $d_p = 112$ µm for L / D = 0.43 for with and without sound intensity. The operating conditions of the material are shown in Table 1. Since the particles selected for the present study lied between the boundary of A / B, according to Geldart classification, their fluidizability was poor. The high sound intensity has helped fluidization of the material in a proper way.

Fig. 2 and 3 depict the variation of minimum fluidization velocity and bed expansion (H) in absence of sound intensity with superficial gas velocity (U_o). In Fig.2, U_{mf} value was considered only by noting the defluidization points. This was found to be 0.55cm/s.

The bed expansion was recorded by millimeter rule attached to the fluidizing column. From visual observation of bed surface it was noted that bed particle showed poor response to the fluidizing gas and gave channels. Further, with increase in gas velocity particles elutriated with decrease in pressure drop. The details of bed expansion in absence of acoustic field are presented in Fig.3.

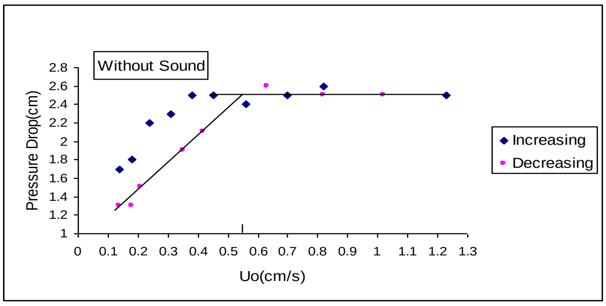

Fig. 2: Variation of pressure drop with gas velocity in absence of sound intensity

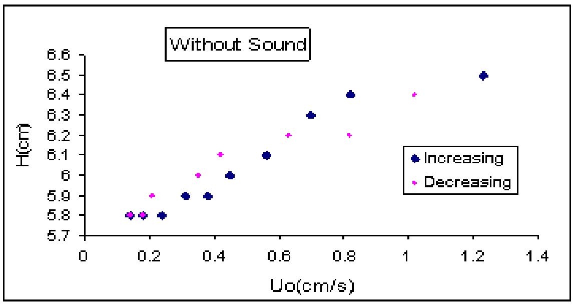

Fig.3: Variation of bed expansion with gas velocity without sound intensity

3.2 Fluidization with the help of sound intensity

During fluidization of silica gel, acoustic field was varied from 120 and 145 dB. From visual observation it was seen that silica gel particles responded to sound intensity from 120 dB. When sound intensity was applied, it gave homogeneous fluidization at higher gas velocity and lower sound intensity. As sound intensity was increased further, quality of fluidization was improved and with further increase resulted in a decrease in minimum fluidization velocity. Figure 4(a, b) shows the variation of minimum fluidization velocity. It clearly indicates a decrease in U_{mfs} when sound intensity was increased from 120 dB to 140 dB.

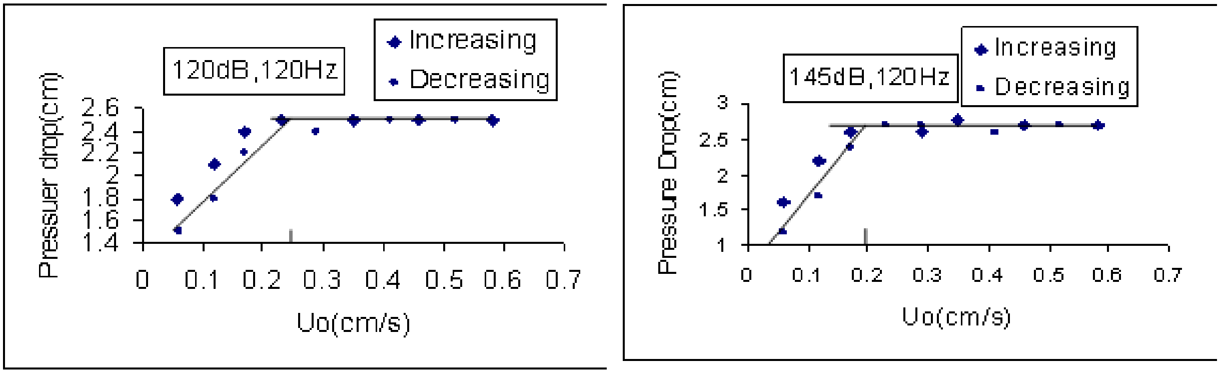

Fig. 4 (a, b): Variation of minimum fluidization velocity for 120 and 145 dB.

3.3 Effect of acoustic frequency on the fluidization properties of material

During experimentation of fluidization of silica gel, effect of variation of acoustic frequency (f) was also investigated. The bed was tested with the frequency range was 90 Hz to 170 Hz by keeping sound pressure level constant i.e. from 120 dB to 145 dB. The column of fluidized bed at 120 Hz frequency was found to give maximum response to the minimum fluidization level due to acoustic resonance. It was observed experimentally that quality of fluidization was adequate at 120 Hz for all ranges of sound pressure level investigated in this study. Fig.5 gives variation of U_{mfs} with change in frequency from 90 Hz to 170 Hz. From these plots of variation, it is noted that U_{mfs} first decreases and then increases with increase in frequency as seen for 145 dB.

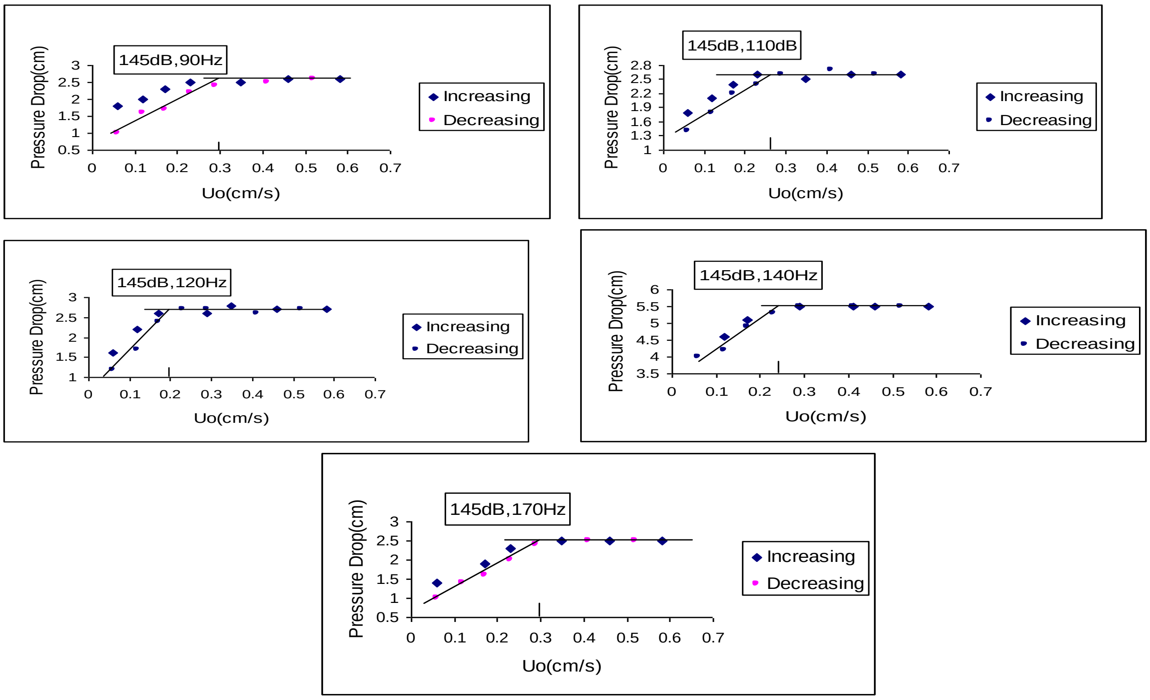

Fig. 5 (a to e): Variation of pressure drop with gas velocity when sound intensity applied at 145 dB and frequencies from 90 to 170 Hz

3.5 Bed expansion

When sound intensity was applied, acoustic waves broke the cluster of particles into subcluster and provided easy passage to the particle to move upward. Hence, low gas velocity was sufficient to give good bed expansion. During expansion process bed particles moved like whirl at U_o = 0.82 cm/s and sound intensity at 140 dB. Then after, with further increase in gas velocity the diameter of whirl increased up to the column diameter. It was also noticed that particles came up vertically from one side of the bed and moved back from the opposite side of the bed. The bed expansion was almost double the static bed height (H) with no elutriation at U_o = 0.62 cm/s. The detailed variation of bed height verses gas velocity is depicted in Fig. 6.

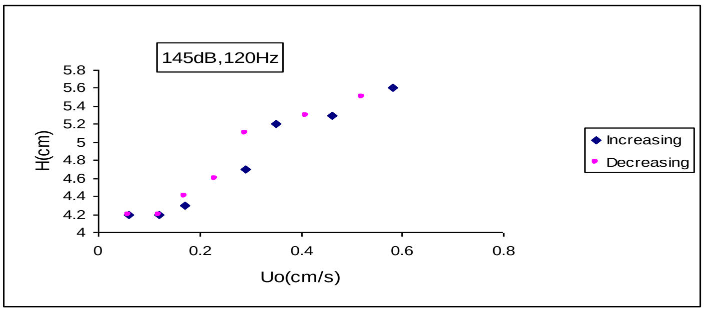

Fig.6: Variation of bed expansion with superficial gas velocity (U_o)

IV. CONCLUSIONS

Experiments were performed with group A / B particles having a mean diameter of approximately 112 µm. When material was demonstrated in fluidized bed up to 145 dB, it has been seen that bed particles give good response to this acoustic field. It was revealed that as sound intensity increases minimum fluidization velocity decreases. It was further noted that sound intensity at 120 dB was sufficient to break the cluster of particles in to subcluster. The best effect has been observed at 145 dB and 120 Hz.

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