EFFECTS OF FREQUENCY OF VIBRATION ON THE SEGREGATION OF GRANULAR MATERIALS


Department of Electrical Engineering, School of Engineering, Abubakar Tatari Ali Polytechnic, Bauchi. Email: tjkuda07@yahoo.com

ABSTRACT

The effect of frequency on the segregation of large spheres in a granular bed under vertical vibrations is studied. Segregation of granular materials is a problem of great consequence in industries involved with the handling and processing of granular materials in which homogeneity is generally required. In our experiments, we systematically measure rise times of the intruder particle as a function of frequency. The measurements reveal that: at constant acceleration the segregation was found to decrease in the frequency range of 20 - 40 Hz and then increases with increasing frequency. However, with increasing acceleration, the segregation decreases in the frequency range of 20 - 40 Hz and then starts to decrease exponentially with increasing frequency.

KEYWORDS: Segregation; Granular Materials; Vibration; Intruder Particle; Acceleration; Convection.

1. INTRODUCTION

Segregation is a process in which a homogeneous bulk solid composed of various constituents or species becomes spatially nonuniform as a result of relative movement within the material. In his contribution, Hogg (2009) reported segregation as being caused by the difference in the basic particle characteristics which can be defined in terms of size, shape, composition and structure. Researchers have carried out a number of studies that demonstrate some of the important features of granular material segregation due to vibration. As reported by Rosato et al. (2002) in one of the first systematic experiments on the effect of vibration frequency on the motion of a single large sphere in a granular bed, sand was vibrated vertically. It was found that the single large particle was always observed to rise to the top. The reason the single large particle rising to the top was that the small sand particles below it are stationary and prevent it from falling, while the particles on the side and top move. Thus, as the large single particle experiences upward movement during vibration, then the small particles flow underneath, causing the large particle to ascend to the top. This was also the view of Rosato et al. (1987) on Brazil nuts.

With the aid of detailed experiments, Rosato et al. (1987) proposed that the geometrical mechanism was responsible for the size separation in a vibrated granular medium. They adapted the Monte Carlo (MC) simulation technique used in statistical physics to show that local geometrical void filling can lead to size segregation with larger particles - the Brazil nut effect. According to Knight et al. (1993) segregation is driven by convection. It was observed that boundaries can have a significant impact on segregation; this is because the frictional interaction of grains with the side walls can set up convection which can cause the large particles to even go to the bottom depending on the shape of the container. Majid and Walzel (2009) reported that “by tilting the side walls of the container outwards, the direction of the convection cells can be reversed”. In addition, Mao-bin et al. (2005) studied the effects of container geometry on granular segregation pattern due to vibration in a set of quasi-two-dimensional container. It was observed that depending on the bending degree, three segregation patterns could be identified: two side-segregation pattern, a left-hand side segregation pattern and a pattern where the big
particles aggregate to the upper left part of the container. Based on molecular dynamic simulations, Kong et al. (2006) investigated the effects of vibration frequency on intruder’s position in granular bed. By varying the vibration frequency at fixed acceleration, it was found that “at relatively low frequency, big particles move upwards towards the centre as if they seep through the assembly; at sufficiently high frequency, big particles move up again and stay at certain height of the granular bed”.

An important experiment performed by Ahmad and Smalley (1973) investigating the effects of vibration frequency and acceleration on the rise time of a single large particle in vibrated granular systems revealed several important behaviours that are worthy to note. At constant acceleration, the rise time was observed to increase with increase in frequency within a certain range. Furthermore, at constant frequency of vibration, the rise time was observed to decrease with increasing acceleration. However, at higher frequency the rise time was increased within the same range of acceleration. It could be deduced from this that acceleration appears to be a critical parameter in controlling the segregation of large particles within a certain range of frequency. Although, in the experiments referred to above, density and size effects were dominant, it was observed that the shape of the large particle of the same mass may not have significant effect on the segregation rate of the particle. Rosato et al. (2002) systematically investigated the effects of vibration frequency and amplitude experimentally using radioactive tracer powders. The importance of particle properties as well as vibration frequency and amplitude on the segregation phenomenon was observed. This is also the view of Ahmad and Smalley (1973).

Based on the foregoing, the current study will focus on the investigation of the phenomenon of segregation under harmonic excitation and at different granular bed depths.

### 2. MATERIALS AND METHOD

#### 2.1 Experimental Set up

The experiment method used in this research was adopted from the work of Ahmad and Smalley (1973). In this experimental set up, a Perspex box was mounted on the air-cooled vibration exciter (LDS V455) plate through the spacer and the base plate using the screw set (bolt and nut, 6mm), which is used to generate the sine vector force. The vibration exciter was placed on an isolator platform to prevent the measuring signals from other source of noise from the general surroundings. The LDS V455 is driven through a 1400 VA, LDS PA 1000L amplifier which amplifiers the signal of 400mV amplitude from the sine square oscillator at the chosen test frequency. An accelerometer is mounted on the base plate to measure the acceleration. A cooling fan was connected to the vibrator, to prevent the vibrator from being over heated. The experimental setup is presented in Figure 1.

In this set up, Data acquisition is by means of the accelerometer connected to the PC. Communication between the accelerometer and the PC was achieved using NI USB-9162 data acquisition (DAQ) device. The operation of the DAQ is controlled with the student edition of the LabVIEW 8.5 Software. The program includes the relevant VI’s for the vibration level measurement and the elapsed time VI that counts the time once the LabVIEW program has started running. The acceleration magnitude can be set by adjusting the gain control knob of the PA 1000L amplifier and monitored on the LabVIEW program.
2.2 Experimental Procedure
Experiments were carried out in the Perspex box set up as shown on Figure 1.0. At the start of each experiment, the intruder particle was placed carefully at the bottom centre of the Perspex box which was then filled with dry sand to a height of 75 mm, 100 mm and 125 mm respectively. For a signal level 0.4 V (400 mV) peak to peak from the signal generator, the Perspex box was first vibrated sinusoidally over a range of frequencies from 20 Hz to 100 Hz in the vertical direction with a fixed acceleration of 4g and 5g respectfully. Within this range of frequencies, the accelerometer was precise and independent of its structural resonance. The application of the vibration to the Perspex box was made concurrently with the running of the LabVIEW program start button of the stop watch counter.

The motion of the intruder particle through the granular bed was observed by direct visualization and upon reaching the top surface, the LabVIEW program stopwatch counter will be stopped and the elapsed time VI returns the value of the time it takes the intruder to reach the top surface. When the experiment was completed, the dry sand particles were removed from the Perspex box by loosening the nuts which were used to mount the Perspex box onto the base plate and as well the large intruder particle is removed from the bulk particles (dry sand). The experimental procedure is repeated for the next experimental run.

3. RESULTS AND DISCUSSION

3.1 Effect of frequency at constant acceleration
Because Kong et al. (2006) suggested that vibration frequency is a significant parameter affecting the segregation process for fixed vibration acceleration; this has been examined in detail for the various intruder particles and is shown on Figures 2 - 10. Although because they used small frequency range (20 Hz – 65 Hz) than the range used in this study, the effect of the variation of the frequency was still observed.
Figure 2: Effect of frequency of vibration on segregation

Depth of bed = 75mm. position of large particle: silica glass of size 6mm placed at bottom centre position. Vibration conditions: fixed acceleration of 4g and 5g but variable frequency.

Figure 3: Effect of frequency of vibration on segregation

Depth of bed = 100mm. position of large particle: silica glass of size 6mm placed at bottom centre position. Vibration conditions: fixed acceleration of 4g and 5g but variable frequency.
Figure 4: Effect of frequency of vibration on segregation

Depth of bed = 125 mm; position of large particle: silica glass of size 6 mm placed at bottom centre position; Vibration conditions: fixed acceleration of 4g and 5g but variable frequency

Figure 5.0 Effect of frequency of vibration on segregation

Depth of bed = 75 mm, position of large particle: nylon of size 6mm placed at bottom centre position. Vibration conditions: fixed acceleration of 4g and 5g but variable frequency
**Figure 6: Effect of frequency of vibration on segregation**

Depth of bed = 100mm, position of large particle: Nylon of size 6mm placed at bottom centre position.
Vibration conditions: fixed acceleration of 4g and 5g but variable frequency

**Figure 7: Effect of frequency of vibration on segregation**

Depth of bed = 125mm, position of large particle: Nylon of size 6mm placed at bottom centre position.
Vibration conditions: fixed acceleration of 4g and 5g but variable frequency.
Figure 8: Effect of frequency of vibration on segregation

Depth of bed = 75mm, position of large particle: silica glass of size 3mm placed at bottom centre position. Vibration conditions: fixed acceleration of 4g and 5g but variable frequency.

Figure 9: Effect of frequency of vibration on segregation

Depth of bed = 100mm, position of large particle: silica glass of size 3mm placed at bottom centre position. Vibration conditions: fixed acceleration of 4g and 5g but variable frequency.
As can be seen from these Figures, a very interesting behaviour is found. In these Figures the rise time of the intruder for different experiments is plotted against the frequency. Generally, it was found that the segregation time is decreased (hence segregation is increased) with increasing frequency in the frequency range 20 Hz – 40 Hz. However, beyond that range, the behaviour is counter-intuitive as the segregation time is increased with frequency. Gross motion of the bed reveals that the changing behaviour may be attributed to the change in flow regime. Below 40 Hz, the flow regime is convection and heap type, while above 40 Hz, the flow regime is surface fluidisation with apparently random motion and no heaping occurs. Furthermore, it became evident that, at higher frequency the bulk density of the bed increases and the intruder takes longer time before reaching the top surface. However, increasing the acceleration level to 5g increases the segregation in general. Hence it could be conclude that the acceleration could be a critical parameter in controlling segregation.

Moreover, it was observed that at higher frequencies, once the large intruder particle has reached the top surface, it will stay there because the convection currents are too narrow to sweep it down along the wall.

3.2 Discussion
A series of results for the rise of a single large intruder particle in a granular bed consisting of small dry sand particles are presented. These preliminary results represent a part of the ongoing experimental investigation of vibrated granular beds and in particular the Brazil Nut Effect (BNE) or size segregation. As it has always being the case that when granular beds are subjected to vibrations, the large particles were observed to rise to the top surface, though the underlying mechanisms behind it have been the subject of disagreement among a number of researchers. Rosato et al. (2002) argued that the large particle rises to the top due to the void filling mechanism in which smaller particles fall into the voids created underneath the large particles. In addition Yan et al. (2003) and MÖbius et al. (2008) proposed that in granular bed consisting of fine particles, air-driven effects contribute to the rise of the large particle to the top surface.

The results presented here corroborate some of the work previously reported by others. The important observation is that frequency appears to be a significant parameter affecting such studies, as indicated by the graphs of the rise time plotted as a function of the frequency. It was found that at constant acceleration as the frequency increases, the segregation decreases within a certain range and as the acceleration increases, the segregation...
experimental results of Ahmad and Smalley (1973). Moreover, it was evident from Figure 2.0 through Figure 10.0 that at frequency range of 20 Hz – 40 Hz the segregation increases with frequency and beyond 40 Hz segregation decreases with increase in frequency. This is due to the different flow regimes existing between the ranges. This assertion was similar to the experimental results of Vanel et al. (1997), where a 3 mm acrylic sphere in a cylindrical container were agitated through sinusoidal oscillations of a floor piston at displacement amplitude \( a_o \) and vibration frequency \( f \). In the experiment referred to above, three flow regimes characterised by the vibration parameters were observed. At frequency of \( f \leq 15 \text{ Hz} \), strong convective flow and surface heaping was observed. In this regime \( T_f \) scales exponentially with \( f \). In the second regime (15 Hz < \( f \) < 40 Hz), surface heaping was no longer observed but still convection provides the driving mechanism and in the third regime (between 40 Hz and 75 Hz) the amplitude of vibration becomes much smaller than the diameter of the bed particles, in this case the bed experiences an increase in bulk density and the intruder takes longer time to reach to the top surface. This regime is characterised as the non-convective regime. However, in theory acceleration is given by \( A w^2 \) (\( w = 2\pi f \)). From this, it could be deduced that as the frequency increases at constant acceleration, the amplitude becomes relatively small. The net result is that the bed will become compacted and the intruder particle slowly rises to the top surface.

4. CONCLUSION

This study investigated the segregation of granular materials due to vibration. The experiments involving the motion of large single particle through a dry granular bed under vertical vibration were carried out. The effects of frequency on the segregation phenomenon were investigated. Silica glass (size: 3mm and 6mm) and Nylon (6mm) were the particles used in the study. Based on the experimental results, it was observed that the frequency of vibration appears to be a significant parameter affecting the segregation process at constant acceleration. Moreover, it was also observed that as the frequency of vibration increases, the segregation decreases within a certain range at constant acceleration.

REFERENCES


Kuda et al. (2014)
