An experimental study: mixing rate of granular materials under vertical vibration

P Chaiworn* and K Kiengmana

Department of Physics, Faculty of Science and Technology, Chiang Mai Rajabhat University
*E-mail: panupat_cha@g.cmru.ac.th

Abstract. This research aims to the master development result of learning in mixing ratio and quickly rate of mixing granular material for elementary study apply and development of mixing ratio industry and agriculture. The researcher separate 2 parts of mixing ratio put low dense material on the top and high dense material on the top with frequencies from 6, 7 and 8 Hz, Recording 60 s. of picture frame. Counting the mixing granular material in different high in container. Calculating the percentage of mixing in each different high, mixing rate 0 – 1 different of each experiment. Material used ceramics (1.61 g/cm$^3$), plastic (0.98 g/cm$^3$) and wood (0.72 g/cm$^3$). It was found that more frequency better mixing, the high dense granular material on the top is mixing rate better than the low dense granular material on the top. In the time at 40 – 60 s. were the best of mixing rate, mixing granular material with different time in each frequency. The movement of granular material able to occurs in many form, disperse, clumping and spin and roll. Furthermore, the low dense granular much more quickly movement. Conclude that density, position, frequency and time effect to mixing. Frequency very with quickly but inverse with density of material and the materials were mixed at its best in each period of time different.

1. Introduction
In the era of globalization, people, goods, money, labors, knowledge, and news are able to travel freely and rapidly around the world. It became a phenomenon that has never seen before [1]. Each era has been developed from agricultural era, industrial era, and informational era. Our world has been gradually developed until the technology can provide more convenience. Industry has been one of the most important aspect to development of prosperity and better quality of human’s life. Most of the facilities used nowadays are the results of the progressive technology. The production process also requires separating and mixing of particles leading to the combination and connection of particles to form the products that has been used nowadays. In the study of mixture and the characteristics of the product components in terms of chemistry and physics, granular materials are combined with small material with gaps allowing water or air to run through [2]. Granular materials are important in a variety of industries. In the production process, the materials may be vibrated to mix or separate. Once they are vibrated, many interesting phenomena occurred and they are worth to study such as arching, mixing, heaping, segregation, surface waves, convection, and others. The body of knowledge in fluid mechanics is required to study this issue. For this reason, we are interested in mixing rate of granular materials under vertical vibration. The density of the materials were different or different materials were used. The experiment was conducted in two-dimension system. The results were compared and considered the movement and the mixing rate of each density [3]. He important purpose of this project
was to study mixing rate, the movement of the material and velocity rate of mixing material so that this body of knowledge can be applied in the mixture onwards.

2. Research methodology

2.1. The mixing rate of granular material

The vertical vibrator was installed and tested. (shown in figure 1) The cylinder container with 6 cm of the diameters with the height of 11 cm was designed to mix the granular materials of the same size and density. Different materials with the same size such as ceramic, plastic, and wood were used. The experiment to mix the two materials which were wood-plastic, plastic-ceramic, plastic-wood, and ceramic-plastic. The controlled amplitude was at 15 mm and the frequencies were 6, 7 and 8 Hz. [4] The video was recorded during the experiment which was observed to follow the movement of the mixing granular material. The results were recorded to follow the mixing rate. The mixing was conducted 10 s per one around starting from 0 to 60 s. The results were then analyzed and summarized.

2.2. The movement of the granular materials

The movement of the granular materials in cylinder container under vertical vibration was conducted at the same time as item 1. The analysis of the movement, the convection, and the mixing of the granular materials. [5] When the materials were vibrated, convection occurred. The photos of the process were taken continuously for 60 s. The granular materials under the convection, mixing and segregation led to different movement of the materials [6].

2.3. Velocity rate of mixing the granular materials

The velocity rate of the moving granular materials with its density between plastic-ceramic, ceramic-wood and wood-ceramic with the controlled frequencies of 6, 7, 8 Hz. The velocity rate of the moving granular materials in cylinder container under vertical vibration was conducted at the same time as item 1. Tracker version 4.96 was used.

Figure 1. Schematic drawing of the vibration granular materials.

3. Results and discussion

3.1. The study of density and density ratio of the granular materials

Different granular materials with the same size (diameter of 0.6 cm) were used in the experiment to identify the density and density ratio of the granular materials in order to study mixing and segregating of the granular materials under vertical vibration as shown in table 1. It was found that among the three kinds of granular materials, ceramic (1.61 g/cm$^3$) has the highest density. Plastic (0.98 g/cm$^3$) and wood (0.72 g/cm$^3$) were respectively subordinated density. After that, the density ratio of the mixed granular materials was identified as shown in table 2.
Table 1. The Density of Granular Materials.

| Granular particles | Style       |
|--------------------|-------------|
| Wood               | 0.72±0.20   |
| Plastic            | 0.98±0.12   |
| Ceramic            | 1.61±0.15   |

Table 2. The Ratio of the Density of the Mixed Granular Materials.

| Mixing        | Density ratio |
|---------------|---------------|
| (Upper) – (Lower) | (ρ_up/ρ_down) |
| Wood – Ceramic | 0.45          |
| Wood – Plastic | 0.73          |
| Plastic – Ceramic | 0.61     |
| Plastic – Wood | 1.36          |
| Ceramic – Plastic | 1.64     |
| Ceramic – Wood | 2.24          |

3.2. Mixing ratio of the granular materials
The mixing granular materials in the container under the vertical vibration led to the study of mixing ratio of the granular materials. The materials used were wood, plastic, ceramic that were mixed under the frequencies of 6, 7 and 8 Hz. The photos of this process were taken for 60 s. The granular materials mixed in the container were counted. The mixing ratio based on the percentage of the ratio starting from 0-1 [7]. The researchers divided the graph into 3 ranges which were 6, 7 and 8 Hz. According to figure 2, it was found that the mixture of wood-plastic would be better at t=30 s with the frequency of 6 Hz. However, the mixture was not much but at the same time when the frequency was at 7 and 8 Hz, the materials were mixed more and better than the mix at 6 Hz and at t= 60 s, the mixture was better in every frequency. Furthermore, according to figure 3, it was found that in the same period of mixed plastic-ceramic at t=20 s at the frequencies of 6 Hz would not be mixed. It was cleared separated in layers starting from frequency 7 and 8 Hz. The plastics were mixed more than ceramic and it was not mixed well. However, at t= 60 s, the materials were well mixed in every frequency. Therefore, it can be summarized that materials were mixed better. Furthermore, when the materials were denser on the upper part. It was also found that the materials were mixed better and more rapidly. According to figure 4, the mixed plastic-wood at t=30 s at the frequency of 6 Hz. The wood mixture moved to the upper part and the middle part in the container was mixed. However, the materials were not mixed at all at the bottom part of the container [3]. Similarly, the frequencies of 7 and 8 Hz at t= 60 s were resulted in the best mixing at 7 Hz. With the frequency of 6 Hz, the materials were not mixed and according to figure 5 shown the ceramic-plastic mix at t=40 s, it was found that plastic would move to the upper part and some materials would stay in the bottom of the container [8]. It showed that the plastics were moved as a group but they were still mixed; however, the plastics were more than the ceramic at the observation point. Similarly, at t=60 s, the materials were in the same group.
Figure 2. The ratio of the wood-plastic with the height at (a) $t = 0$ s, (b) $t = 30$ s and (c) $t = 60$ s.

Figure 3. The ratio of the plastic-ceramic with the height at (a) $t = 0$ s, (b) $t = 30$ s and (c) $t = 60$ s.

Figure 4. The ratio of mixing of plastic-wood with height at (a) $t = 0$ s, (b) $t = 30$ s and (c) $t = 60$ s.

Figure 5. The mixing ratio of ceramic-plastic with height at (a) $t = 0$ s, (b) $t = 30$ s and (c) $t = 60$ s.
When the time was divided into 4 ranges which were the frequency at 0, 20, 40 and 60 Hz as shown in figure 6, it was found that the frequency of 6 Hz led to the obvious difference in each period of time. At t=0-40 s., the granular materials were not mixed well and they were separated in layers of wood-plastic. At t= 60 s., the mixing ratio was at its best with the frequency of 7 Hz. At t = 20 s, the materials were mixed well until the time at 60 s. The mixing process got better continuously and they began not to separate. At the frequency of 8 Hz, the materials were mixed at its best in each period of time. When the density was considered, it was found that the mixing ratio of wood-plastic at the frequency of 6 Hz caused less mixing. The layers were clearly separated the materials in each time period and the materials were not mixed at the frequency of 7 Hz. At t=20 s, the materials were mixed better. At t= 60 s, the materials were better constantly. However, the wood that had lower density would not be mixed at the frequency of 8 Hz. The mixing ratio was at its best in each period of time; however, the wood would be at the lower part of the container and it was not mixed at every period of time. Therefore, it can be concluded that the materials were mixed better when the frequencies were higher and the mixing in each period of time was different in each frequency and the materials were less dense and stayed at the lower part of the container. And shown in figure 7, it was found that the all frequency of 6, 7, and 8 Hz led to the obvious difference in each period of time. At t=0-20 s, the granular materials were mixed well and they were separated in layers of ceramic-wood, the mixing ratio of the ceramic-wood with the height at t= 20 s, the mixing ratio was at its best with the frequency of 8 Hz. At t = 20 s, the materials were mixed well until the time at 20 s. The mixing process got better continuously and they began not to separate. At the frequency of 8 Hz, the materials were mixed at its best in each period of time. When the density was considered, it was found that the mixing ratio of ceramic-wood at the frequency of 6 Hz caused less mixing. The layers were clearly separated the materials in each time period at t=20 s, the materials were mixed better. At t= 60 s, the materials were better constantly.

Figure 6. The ratio of mixing wood-plastic with height at (a) f=6 Hz, (b) f=7 Hz and (c) f=8 Hz.

Figure 7. The mixing ratio of the ceramic-wood with the height at (a) f=6 Hz, (b) f=7 Hz and (c) f=8 Hz.
3.3. The movement of the mixing granular materials

The granular materials with different density in the same size. The materials were placed in cylinder container and they were vibrated under vertical vibration using the frequency of 7 Hz. The photos of the entire process were taken continuously for t=60 s. It was found that at t=30-60 s, the materials with more density would be on the top of the container. The mixing would be different in each frequency. It can be explained that the mixing of the granular materials. The fluctuation with the density of the materials. It can be classified into materials, frequency, and heaping. The materials with lower density would be on the top part of the container which was wood-ceramic (figure 8 (a)) and the wood-plastic (figure 8 (b)) with the frequency of 7 Hz [9]. The movement started at t = 0 s when the time passed at t=10 s, the wooden materials were moved to the bottom part of the container. At t=20 s, the materials started to get mixed. The wooden materials were moved to t=30 s. Later on, the materials were mixed well as shown in figure 8.

![Figure 8](image1.png)

**Figure 8.** The mixing of the granular materials at f = 7 Hz (a) wood-plastic and (b) wood-plastic.

![Figure 9](image2.png)

**Figure 9.** The mixing of the materials at f = 7 Hz (a) ceramic-plastic and (b) wood-plastic.

The movement was the mix of ceramic-plastic (shown in figure 9 (a)) and the wood-plastic (shown in figure 9 (b)) with the frequency of 7 Hz. The materials with more density were on the upper part of the container. It was found that the movement was in circular motion with t=20 s and the movement were in a group of the material. The ceramic which was the material with more density would move to the bottom of the container [10]. The movement were in group and in circular motion between the period of time at 30-60 s which was the velocity ratio of mixing, the density of the mixed materials, and the different frequencies affecting the movement of the materials as show in figure 9. When the materials with the different density but in the same size were used in the container under the vertical...
vibration with the frequencies of 6, 7 and 8 Hz. The photos were taken constantly for 60 s [11]. It was found that the frequencies were increased when the materials were mixed more. The ratio of the moving materials would be increased when the materials were mixed starting from 0-60 s. It can be seen that the frequencies were directly fluctuated with the velocity ratio and there was no relationship with the period and the movement as shown in figure 10. When considering the velocity ratio with the mixed density of the materials with the same frequencies, it was found that the material with lower density would move faster than the materials with more density. It can be seen that the frequencies were directly fluctuated with the velocity ratio as shown in figure 11.

![Figure 10](image1.png)  ![Figure 11](image2.png)

**Figure 10.** The velocity ratio and time with different frequencies (a) ceramic (b) plastic and (c) wood.

**Figure 11.** The velocity ratio with time for the different material (a) plastic-ceramic, (b) wood-plastic and (c) wood-ceramic.

4. Conclusion
According to the density and the ratio of the materials mixed under the conditions for the density of the three materials, it was found that the density of ceramic was the highest density of (1.61 g/cm³). After that, it was plastic (98.0 g/cm³) and wood (0.72 g/cm³) respectively. The ratio of the density of the mixed materials of wood-ceramic would be the most different. The mixture of wood and plastic materials was the closest. Moreover, the mixing ratio of the granular materials was different. When the frequencies were increased, the mixing process was better and the materials with more density would be on the upper part of the container [12]. Therefore, the density of the granular materials and the heaping of the materials affected the fluctuation of the frequencies and the mixture. The movement of the materials occurred in many forms such as dispersing, grouping, and circulating. At the second of t=40–60 s, the materials with more density would be on the topper part and it would move faster to mix with other materials. It can be explained that the density of the materials and the materials were mixed with frequencies. It affected the mixing and the fluctuation of the frequencies. The ratio of the moving increased and the materials were dense. It showed that the ratio of the velocity directly fluctuated the frequencies but it inverses with the density of the materials. This concept was applied and analyzed in the industry or other aspects. It supports the theory of granular materials and the experiment related to the granular materials.
Acknowledgments
This work was successfully conducted, I feel grateful for the research fund and support from Faculty of Science and Technology, Chiang Mai Rajabhat University.

References
[1] Heinrich M J, Sidney R N and Robert P B 1996 Rev. Mod. Phys. 68 1259
[2] Gray J M N T 2017 Annu. Rev. Fluid Mech. 50 407
[3] Lu L S and Hsiau S S 2008 Powder Technol. 184 31
[4] Laura A, G and Karen E D 2009 Phys. Rev. E 80 042301
[5] Duran J 1999 Sands, Powders and Grains an Introduction to the Physics of Granular Materials translated by A Reisinger (New York: Springer-Verlag New York)
[6] Joseph J, Devang V and Julio M 2000 Powder Technol. 109 72
[7] Stefan R, Daniel B, Hanna H, Benjamin J G and Johannes G K 2012 Powder Technol. 226 199
[8] Metcalfe G and Shattuck M 1996 Physica A 233 709
[9] Haojie F, Daochuan G, Jiancong D, Xuan C, Mingchuan Z and Zhongxiao Z 2018 Powder Technol. 327 223
[10] Chaiworn P 2011 Granular Matter 13 379
[11] McNamara S and Luding S 1999 A simple method to mix granular materials IUTAM Symposium on Segregation in Granular Flows (vol 81) ed A Rosato and D L Blackmore (Dordrecht: Springer) p 305
[12] Yang S C 2006 Powder Technol. 164 65