Department of Materials Science and Metallurgical Engineering

NMP 310 - Minerals Processing

Practical 5: Gravity Concentration - Shaking Table

by
Group 4 (Metallurgical and Mining Engineering)

S.S. Ndimande (14202604)
U. Durgean (12274489)
J. Labuschagne (14048460)
N.N. Buthelezi (14199123)
J. Nam (14268770)
J.D. Hulley (14350018)
I. Khoza (13246713)

Date of Practical: 09 March 2016

Date of Submission: 15 March 2016

Abstract

The experiment investigates the separation of materials of different densities on a shaking table. The variables that affect the efficiency of separation are the material feed rate, water flow rate, slope of the deck and the frequency of the vibration of the table. However, in this investigation, the feed rate is kept constant at 22.17 g/minute, the water flow rate at 0.21 litres/second and the slope of the deck at 19°. For simplicity, the frequency is the only variable of the experiment.

When the frequency was set at 30 Hz, the grade of the concentrate was not as good as it was expected. Since the recovery was a low 58%, it was expected for the grade to be high since the grade-recovery relationship is typically inversely proportional. Also, considering that the separation process lasted for more than 2 hours, it was expected that ample time was allowed for excellent separation. However, this was not the case. Surprisingly, the experiment at higher frequency (40 Hz) resulted in a higher grade concentrate i.e 30% versus 28%. This is surprising also because the separation profile was more uniform at the lower frequency compared to when the rate of oscillations was higher.

On a large scale, the 40 Hz process should be more preferable. The separation process consumes less water, energy, and takes a relatively shorter amount of time. It would therefore be more economical.

Contents

List of Figures

Chapter 1

Introduction

One of the functions of minerals processing, is concentration. Concentration may be simply defined as the upgrading of a mineral. That is, to increase the fraction of the valuable material versus the discard material. This may be achieved with a host of different processes. What these methods have in common is that they take into consideration the physical properties of the material(s) of interest. Of course, unlike processes in pyro-metallurgy and hydro-metallurgy, which take into account the chemical properties of ore material. In this investigation, the primary physical property considered relates closely with gravity; density. Second to that, is the texture (and size) of the material - which also affects the efficiency of the separation mechanism, specifically, on a shaking table.

Three 100g samples with a composition of 25% ilmenite ($FeTiO_3$) and 75% silica (SiO_2) are separated on a shaking table. To simplify the experiment, certain operating conditions are kept constant. The feed rate is kept at 22.17 g/minute, the slope of the deck is maintained at 19°, and the water flow rate is kept in the vicinity of 0.21 litres/second. The only variable is the frequency of the table's vibrations.

Ilmenite is heavier than silica. The expectation is that the ilmenite particles will settle at the bottom of ridges in-between riffles. The silica particles, as they are closer to the top of the ridges, should be carried by the flowing water towards the tailings launder. On the other hand, the ilmenite particles will travel across the table (in-between the riffles), forming a curved profile as they migrate onto the riffle-less region of the table. Most of the ilmenite is expected to collect in the concentrate launder. The rest of the ilmenite will report in the middlings and in the tailings. It would seem that separation would be best at 30 Hz because ample time would be allowed for ilmenite and silica to separate extensively.

The Aim of The Experiment

The aim of the experiment is to investigate the effect of set operating conditions on the efficiency of separation. Since the feed rate, water flow rate, and deck slope are kept constant, the variable investigated is the frequency of the table's vibration. Moreover, the grades and recoveries of the sub-experiments are compared.

Chapter 2

Background

2.1 Shaking Table

Shaking tables are one of the most environmentally friendly methods of mineral processing as the only reagent used is water. Shaking tables are widely used in commercial mines but have found little use by small-scale miners due to their relatively high cost (Mitchell, C.J., 1997).They utilize both particle density and to a lesser extent particle size to fractionate fine ore samples (<1mm) into products, middlings and waste fractions (Mintek 2016). That is, if a milled ore is introduced into this system, it can be expected to undergo natural sorting wherein high-density particles sink to the bottom and lighter ones float to some extent (M. Tshazi, 2016). With this effect lighter particles then move faster than heavier particles as they are submerged in the faster moving portion of the film (M. Tshazi, 2016).

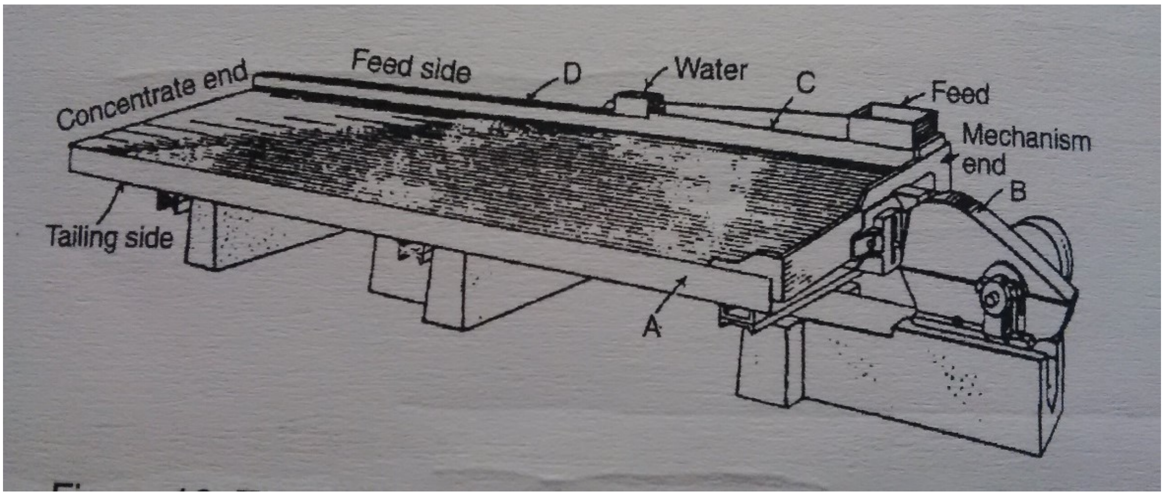

Figure 2.1: The Wilfley shaking table. (M. Tshazi, 2016)

Figure 1, shows the Wilfley shaking table which consists of a transversely sloping rectangular deck A, onto which feed of about 25% wt solids is introduced from the feed box and distributed along C, wash water is dispersed along the balance of the feed side from launder D. The table is vibrated longitudinally by mechanism B using a slow forward stroke and a rapid return. This makes the movement towards the discharge end slow and return fast. An adjustable splitter at the end is often used to separate this product into two fractions – a high grade concentrate and a middlings fraction. (M. Tshazi, 2016)

Separation of the 3 fractions is mainly affected by a number of operating variables like wash water flow rate, feed pulp density, deck slope, amplitude of vibration and feed rate. Particle shape and size distribution also play important roles as well. (M., Tshazi, 2016). Some of the parameters that can influence the grade of the concentrates are briefly explained below:

- An increase in the wash water flow rate, increases the grade of the concentration fraction at both lower and higher feed flow rates. As wash water flow rate increases, the transport of gangue minerals to the tailings fraction increases which in turn improves the grade of the concentration fraction. (Tripathy, S.K., 2010).
- Higher grade of the concentrate fraction is obtained at higher level of both deck tilt angle and feed flow rate. With a lower level of deck tilt angle, an increase in the feed rate decreases the quality of the concentrate fraction (Tripathy, S.K., 2010).

Advantages of the shaking table

- Highly selective, with high upgrading ratio if used correctly.
- Able to see separation and make adjustments. (Falconer, A., 2003)

Disadvantages of the shaking table

- Low capacity, large floor area requirements.
- Require frequent operator attention, checking and adjustments.
- Feed should be sized. (Falconer, A., 2003)

Shaking tables are relatively old equipment but still have a very important place in the mineral processing industry. They typically teat finer material than jigs but at a lower capacity. Shaking tables are still used for coal cleaning of 0-6 mm and also for concentrating heavy non sulfide minerals e.g. cassiterite, scheelite and gold (M. Tshazi, 2016).

2.2 Grade and Recovery

2.2.1 Recovery

The metallurgical recovery is a very important process for the assessment of the value of minerals economically for a mining business. Recovery is defined by the percentage of valuable minerals in the ore which is recovered by metallurgical methods. For example, a mining company has 1000 tons of copper ore and it has 1% copper minerals. Recovery rate is 80%. In this case, amount of copper which can be recovered is 1000*0.01*0.8 = 8 tons.

Theoretical Grade-Recovery

The theoretical grade-recovery for an ore is defined as the maximum predicted recovery by flotation of a mineral at a specific grade. This grade value is determined by the liberation of surface area of the valuable minerals. As a result of previous process, it is directly related to utilization of the grind size in the process. The theoretical grade-recovery can be normally utilized to identify potential recovery quickly and it can help to optimize the flotation process which can be more efficient. (911Metallurgist)

Recovery is described as; R = $\frac{M_{v,c}}{M_{v,o}}$*100 (1)

Concentrate grade is described as; G = $\frac{M_{v,c}}{M_c}$*100 (2)

Where; $M_{v,c}$ - Mass of valuable in concentrate
$M_{v,o}$ - Mass of valuable in ore i.e original sample
M_c - Mass of concentrate

2.3 Magnetic Separation

This is one of the mineral concentration processes. In this process, a mineral which is magnetically susceptible is extracted from a nonmagnetic mixture or a less magnetic mixture of minerals using magnetic force. Magnetic separation can be useful especially in mining iron as it is separated by a magnet. (Mineral Technologies, 2016)

2.3.1 Applications of Magnetic Separation

Wet High Intensity Magnetic Separator (WHIMS)

- From mineral sands, recovery of ilmenite, chromite and monazite uses this machine. They will report to the magnetic fraction and other minerals will report to the non-magnetic fractions.
- It can be used as magnetic gangue removal for many industrial minerals from tin and tungsten ores. (Mineral Technologies)

Induced Roll Magnetic Separators (IRMS)

- From rutile concentrates, it can be used as a removal for ilmenite.
- For final magnetic step of cleaning of zircon.
- It can also be a removal of iron from glass sand minerals and iron mineral from industrial products.
- The semi-lift roll was designed to separate middlings and non-magnetic minerals from magnetic separators; It is especially used in the mineral sands industry. (Mineral Technologies)

Chapter 3

Experimental Set-up

The material and equipment provided:

• A shaking table and water
• Three 100 g samples (25% ilmenite and 75%silica)
• Magnetic separator

The following procedure was followed:

1. Measure the slope of the deck. (19°) This angle is kept constant.
2. Start running the water and measure/adjust its flowrate.
3. Place containers under the holes to collect the tailings, middlings and the concentrate.
4. Place sample in the continuous feeder and calculate the feed rate. Keep this rate constant throughout all experiments.
5. The experiment was done three times at 30 Hz, 37 Hz and 40 Hz.
6. Once the concentrates, middlings and the tailings have been collected for all three frequencies, the samples are to be dried in an oven.
7. They are then fed into the magnetic separator separately.
8. If there is still some mixing of silica and ilmenite, re-feed the contaminated container into the magnetic separator to completely separate.

Figure 3.1: Lab-scale magnetic separator. (SGS.org, 2016)

9. Once again weigh the respective samples, these weights will be used to calculate the grades and recoveries of the three experiments.
10. During the experiments photographs are taken to show the difference in splitting at the various frequencies.

Chapter 4

Results and Discussion

Three samples of 75 g Silica and 25 g ilmenite were separated on a shaking table. Each sample was separated at a different frequency. The results of each separation process are summarised below. On all the images, the dark particles are ilmenite and the light particles are silica.

4.1 Sample 1 - 30 Hertz

Shaking table operating conditions:

Water flow rate: 0.20 dm^3/s
Feed rate : 20.62 g/s
Deck slope : 19°

Product	Magnetics(g)	Non-Magnetics(g)	Total mass(g)	Assay (Wt%)		Recovery % (Magnetics)
				Magnetics	Silica	
Frequency	30Hz					
Concentrates	14.6	36.5	51.1	28.57	71.43	58
Middlings	3.3	21.6	24.9	13.25	86.75	
Tailings	0.9	13.5	14.4	6.25	93.75	

Figure 4.1: Table of results of experiment 1.

Figure 4.2: Profile 1 of separation.

Figure 4.3: Profile 2 of separation.

Figure 4.4: Profile 3 of separation.

The above three images were captured at random times, each representing the separation process for 30 Hz. In figure 4.1, it can be seen that the majority of the silica is reporting to the tailings. As the separation process continues, the ilmenite reports to the middlings and most of it to the concentrate. With recovery as low as 58%, the grade is expected to be high; grade and recovery are generally inversely proportional. However, operating at this frequency was time-consuming.

4.2 Sample 2 - 37 Hertz

Shaking table operating conditions:

Water flow rate: 0.21 dm^3/s
Feed rate : 20.62g/s
Deck Slope : 19°

Product	Magnetics(g)	Non-Magnetics(g)	Total mass(g)	Assay (Wt%)		Recovery % (Magnetics)
				Magnetics	Silica	
Frequency	37Hz					
Concentrates	20	49.5	69.5	28.78	71.22	80
Tailings	0.5	22	22.5	2.22	97.78	

Figure 4.5: Table of results of experiment 2.

Figure 4.6: First separation profile.

Figure 4.7: Second separation profile.

As with the previous experiment, the above images were captured at random times for the separation at 37 Hz. The separation of ilmenite and the silica was quicker than in the previous experiment - the separation profile stays elongated for a shorter period. However, this wasn't without sacrifice. More ilmenite is lost in the middlings and tailings launders than when the frequency was set lower. Recovery is relatively high, therefore it is expected that the grade be lower compared to when the frequency was set at 30 Hz. However, the grades are about the same i.e 28%.

4.3 Sample 3 - 40 Hertz

Shaking table operating conditions:

Water flow rate: 0.20 dm^3/s
Feed rate : 20.62g/s
Deck Slope : 19°

Product	Magnetics(g)	Non-Magnetics(g)	Total mass(g)	Assay (Wt%)		Recovery % (Magnetics)
				Magnetics	Silica	
Frequency	40Hz					
Concentrates	19.4	43.9	63.3	30.65	69.35	77.6
Middlings	0	25	25	0	100	
Tailings	0	3.4	3.4	0	100	

Figure 4.8: Table of results of experiment 3.

Figure 4.9: Separation profile 1.

Operating at a frequency as high as 40Hz, the sample was expected to be poorly separated - considering the amount of time it takes for the process to finish. The profile of the separation was random - not as close to uniform as the profile at frequency of 30 Hz. This particular frequency results in a high recovery of approximately 78%. It is lower that the 40 Hz recovery - therefore, it makes sense that its grade is higher; the grade of ilmenite is 30.65%. It is however, still unapparent why the grade at the frequency of 30 Hz is lower that 30.65%.

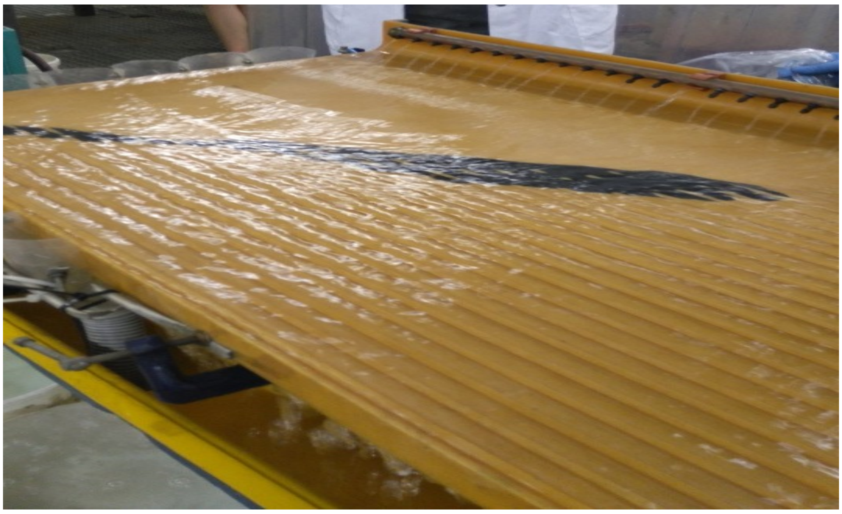

Figure 4.10: Separation profile 2.

Figure 4.11: Separation profile 3.

Based on the results obtained for the various separation processes, one can conclude, that working at a frequency of 40Hz is most effective - the process spans the least period and produces the highest grade. From what was observed and from the pictures taken, it appears that the heavier mineral separates the slowest. That is, even though there is more silica in the sample, for most of the separation process, there is more ilmenite than silica remaining on the table. Also, separation will always occur diagonally regardless of the frequency. Frequency has minimal effect on the material distribution. Material distribution is largely dependent on the deck slope and water flow rate. Steeper decks and fast flowing water concentrate less weight.

Upon performing the experiment, one can deduce that the shaking table has several advantages as well as several disadvantages. The major advantage of shaking tables is the fact that separation can be observed in real-time. This enables changes and allows adjustments to be made, hence improving the next separation process. The disadvantage of using a shaking table is the water consumption. Water is increasingly becoming a rare and expensive commodity. Considering that the 30 Hz experiment lasted for 2 hours and 15 minutes, yet produced a lower grade ilmenite that the 40 Hz experiment - which lasted only 13 minutes.

Chapter 5

Conclusions and Recommendations

In conclusion, it was found that the frequency of vibrations of the shaking table plays a major role in the concentrating of minerals. The experiment carried out at the 40 Hz frequency was the most effective as it produced a higher grade separation in a relatively short amount of time. The 30 Hz frequency was found to be inadvisable for a concentrating plant as the process is time-consuming. In addition, it used up a lot of water yet produced a lower grade concentrate.

From observations, it appeared that the minerals that were the heaviest (and roughest), separated slower than the lighter and finer particles, which were carried by the water easier and rolled on the surface of the table instead of sliding. The mineral with the highest density (ilmenite) sunk while the mineral with the lowest density (silica) floated to some extent. They separated partially due to the slope of the deck and water flow rate. However, the main reason for their separation was their natural differences in density.

Recommendations

Even though the experiment went smoothly, it is plausible to operate at higher frequencies, as the experiment took too long when the frequency was set at 30 Hz. The experiment is not only uneconomical on a plant scale, but the administrator of the experiment should consider increasing the operating frequencies because the experiment lasted longer than the set practical period of 3 hours . The collector buckets should be placed better or replaced with larger containers that will reduce or stop the collected material from washing over and being lost. This will make our results more accurate and more reliable.

Chapter 6

References

1. Mitchell, C.J., Styles, M.T. and Evans, E.J, 1997, The design, construction and testing of a simple shaking table for gold recovery: laboratory testing and field trials, British Geological Survey. url: https://core.ac.uk/download/files/79/58508.pdf (2016-03-12)
2. Mintek Official website, 2016. url: http://www.mintek.co.za/technical-divisions/minerals-processing-mpd/physical-separation/offered-services/ (2016-03-12)
3. Mfesane, T., 2016, Mineral Processing (NMP 310) Practical manual, University of Pretoria.
4. Tripathy, S.K., Ramamurthy, Y., Sahu, G.P., Panda, L., Sing, V. and Tathavadkar, V., 2010, Influence of shaking table process parameters on concentration of chromite plant tailings, Sukinda, COB Plant, Tata Steel Ltd. url: http://eprints.nmlindia.org/2358/1/031.pdf (2016-03-12)
5. Falconer, A., 2003, Gravity Separation: Old Technique/New Methods, Physical Separation in science and Engineering, 2003, Vol. 12, No. 1, pp. 31-48, Taylor & Francis Group. $https : //www.google.co.za/url?sa = t\&rct = j\&q = \&esrc = s\&source = web\&cd = 1\&cad = rja\&uact = 8\&ved = 0ahUKEwi_i9zf_brLAhUBWhoKHUYCDBIQFgggMAA$ (2016-03-12)
6. $http : //mine - engineer.com/mining/minproc/riffle_stratification - on - table.gif$
7. "Magnetic Separation Equipment" $http : //www.mineraltechnologies.com/process-solutions/equipment-design-selection/magnetic-separation$. Visited on 12 March 2016.
8. "WHAT IS A THEORETICAL GRADE-RECOVERY CURVE? AN EXAMPLE." $http : //www.minassist.com.au/blog/what - is - a - theoretical - grade - recovery - curve - an - example/$ Visited on 12 March 2016
9."THEORETICAL Limiting Grade Recovery Curve." $https : //www.911metallurgist.com/blog/what - theoretical - limiting - grade - recovery - curve$ Visited on 12 March 2016
10. Sgs.org.sa. N.p., 2016. Web. 14 Mar. 2016