Parameters which affect the Flow Rate of Minerals through Silos with varying Silo angles and Particle Size

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Abstract: The study was carried out to develop a model for mineral flow rate through conical silos. Dominant factors governing the flow behaviour of minerals through silos were studied. Silo angle and the outlet diameter were identified as the dominant factors of the mineral flow behaviour. Silos were fabricated with half angles varying from 45^0 to 80^0. The range of selection was based on preliminary studies and literature survey. Experiments were carried out for Garnet, Ilmenite, Zircon and Quartz. The initial outlet diameter of the silo was set at 15mm and, then increased gradually by 5mm up to 30mm. Each silo was designed to support up to 15 kg of the mineral. Time taken for a flow 10kg's of each mineral through the silos was obtained while varying the orifice diameter. Results were analysed using Mat-lab and, models were developed for each mineral separately. They show an optimum flow rate of each mineral when the half angle varying in the range between 50^0 to 60^0. The models can be further extended by considering more parameters.

Keywords: mineral flow behaviour, conical silos, orifice diameter.

1. Introduction

Mining, processing, pharmaceutical, cement and packaging industries widely use silos to feed materials. Modern industry utilizes different types of silos designed for various purposes. Conical, pyramid and cylindrical are some instances for physical arrangements of silos. Either the shape can be uniform conflation of above designs.

Improper selection of silos and silo angles result in adverse conditions. It would destruct the continual flow of minerals as minerals get stuck at outlet and as well as some materials will remain on the silo walls without flowing. Therefore, from the industry point of view, it is required to select the most appropriate design in order to maximize the efficiency and reduce the costs.

Prior to the selection of any silo for industrial use, it is vital to carry out a feasibility study regarding the suitability of that silo for that specific purpose. This study should admit both industrial and economic factors in terms of cost.

Flow behaviour of minerals through silos has a great impact on industrial applications. There are two basic types of flows in a silo, namely funnel flow and mass flow. Mineral flow rate through silos is governed by a number of factors [1,2]. There is immense number of researches conducted to study those factors as well as their co-relation with mineral flow rate. Majority of these research are based on dynamic factors of minerals. Still, there is a gap to be bridged regarding the effect of silo factors on mineral flow rate.

From the factors mentioned, study was confined to silo angle and orifice diameter.

The scope of this study is limited to several dominant parameters which were obtained through previous research results and some empirical relationships.

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Shape of the silo, silo angle, roughness of the surface material, orifice diameter, height of the material column, vibration are the external factors governing the mineral flow rate. Moisture content, particle size distribution, surface condition of particles, shape of the particles, density of the particles, cohesiveness of particles, particle moisture absorption are the internal factors controlling the flow of minerals through silos[3].

The ultimate objective of this research is to develop a co-relation between the above parameters and mineral flow rate which would assist to pre-determine the flowability and thereby, attain the maximum production efficiency.

2. Literature Review

Existing mathematical and empirical models were analyzed to identify the pre-dominant factors controlling the flow behavior of minerals. Majority of the existing models were based on empirical studies. Studies were mainly focused on identifying the effect of stagnant zone angle and silo wall inclination to mineral flow behavior. Effect of stagnant zone is greater as the silo wall inclination decreases. When designing the prototype silos, it is indispensable to consider this fact so as to minimize the effect cause by the stagnant zone angle. Literature shows that height of the mineral column inside the silo does not have any effect on the flow rate.

3. Methodology

3.1 Parameters which affect the flow behavior of a mineral through a silo.

A set of parameters which govern the flow rate of minerals through a silo were obtained through literature survey. By using the empirical relationships another set of parameters mentioned above were listed.

3.2 The dominant parameters to the flow behavior of a mineral through a silo

Considering the economic& laboratory feasibility, time frame and industrial demand the selected parameters will further be filtered.
Parameters are filtered and the selected parameter frame is given below.

- Mineral Type
- Silo Angle
- Orifice Diameter

Silos with different silo angles were made to carry a selected weight of a typical mineral. The minerals which are demanded by the industry were selected as feed mineral.
By varying each and every parameter in the above list, the flow rate is observed and the time to collect specific weight interval will be recorded. These results were plotted in a graph and the dominant parameters were obtained.
Finally these results were analyzed in Mat-lab software and models were obtained for each and e mineral.

4. Results

Experiments were conducted to determine the flow rate of corresponding minerals through the silos with different wall inclination. The experimental data were exported to Mat-Lab and obtained the scattered graph. The below figures show the different graphs obtained for four different types of minerals.

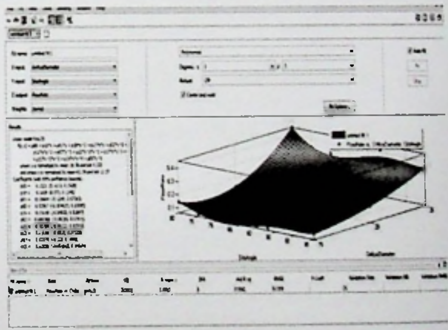

Figure 4.1 - The Best Surface Fit Surface for the mineral Ilmenite

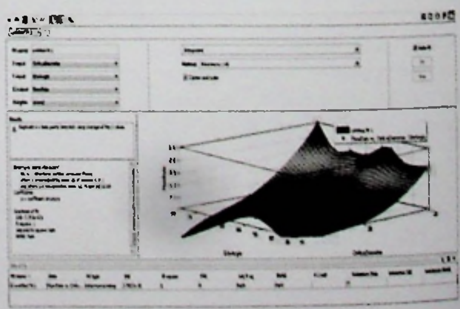

Figure 4. 2 - The Best Surface Fit Surface for the mineral Zircon

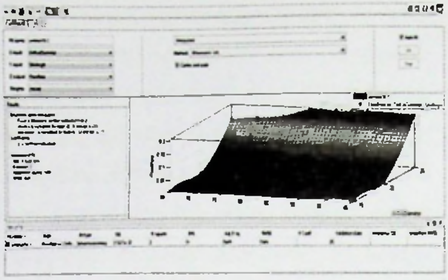

Figure 4.3 - The Best Surface Fit Surface for the mineral Quartz

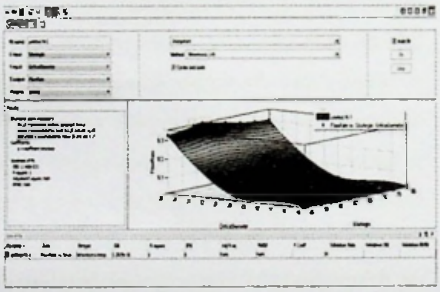

Figure 4. 3 - The Best Surface Fit Surface for the mineral Garnet

5. Discussion

The research was carried out to obtain a model to determine the flow rate of selected minerals to use in industrial applications. The selected minerals those used in modelling are garnet, Ilmenite, zircon and quartz. These are leading industrial minerals which are processed in Sri Lanka and, they are used in multiple number of industries here in Sri Lanka and as well as for exporting purposes. Ceramics, refractory, foundry, metal extraction is the leading industries where these minerals are utilized. Since these minerals are widely used in industries they play a vital role in generating foreign income. It is indispensable to have an idea on the discharge rate of these critical minerals through silos, as it would be of beneficial from the perception of cost optimization and also achieving improved and optimized production processes with high quality products. By implementing optimized discharge rates, we could easily omit the issues such as stagnant of materials in silos, segregation of particles into different sizes and such issues which could result in decreasing the efficiency of production. To eliminate these issues, the silos should be well designed and manufactured in a manner that meets the ideal conditions. In order to meet ideal conditions, we should have the ability to pre-determine the parameters of both silo and mineral, quantitatively, which gives the optimum discharge rate required for the production process. This model facilitates such a relationship between discharge rate and selected parameters.

5.1 Problems faced during designing and experimental stages

During the experimental procedure, silos with different physical parameters were tested for different kinds of minerals. Silos were made using thick hardboards. Prototype silos were made of hardboards to eliminate some of the practical issues that arose during the experimental procedure. It was less cost, ease of make and less time consuming. When selecting the material for silos, some factors considered such as ability to withstand the load, flexibility to some extent to facilitate bending and producing smooth cutting edges to avoid disturbance at the orifice outlet and thereby maintaining a uniform flow. Furthermore, sharp edges will help keep an undisturbed mass flow throughout the experiment. However, there is a limitation with regard to lifetime of the silos as they can be used for limited number of times. Silos were supported using a frame. While designing, sizes of the silo were determined so as to support fifteen kilos of the mineral which possess the lowest density [4].

For experimental purposes, minerals were selected to represent their naturally occurring particle sizes.

Prior to conducting laboratory experiments, each of the mineral samples were oven dried in order to make sure that the samples are dry. Even though the amount of moisture present is a vital factor which affects the discharge rate, it is difficult to determine the behavior of flow rate in accordance with the moisture content due to some practical issues. One major issue is that it is difficult to vary the moisture content with hardboard silos as it gets wet in the presence of water. Also it is rather difficult to control the moisture content and, keep it at a desired level throughout the practical.

5.2 Results Analysis

By Analyzing the equal conditioned Silo factors of different minerals, it is possible to clearly differentiate that the mineral type and Mass Flow Rate has a definite relationship. But this relationship may depend on

- Moisture content
- Repose angle of the mineral
- Friction between mineral particles
- Densities of the minerals
- Particle size distribution

But, these factors were not analyzed due the data obtained from the Literature Review [4,5,6]. At the same time, with the given laboratory conditions, it is not feasible to determine the relationship due to the time frame. Therefore, as a whole, the Mathematical Models for Mass Flow Rate was modelled for different type of minerals separately. By using these models, one can describe the Mass Flow rate of minerals through a silo for a particular mineral. By the obtained data, when comparing the Orifice diameters effect on the Mass Flow Rate, it shows a strong relationship. By increasing the Orifice diameter by 5 mm the Mass Flow Rate can be increased for about 10 times. By Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4, this fact can be clearly perceived. But there are limitations in increasing the orifice diameter due the requirements of the design.

In this context the Silo Angle can be given as the major factor which influencing the Mass Flow Rate of a mineral through the silo. Generally along with the Silo and the Mass Flow Rate gradually increases, but there some exceptions can be seen in the Model. These exceptions were clearly visible around the 50^0-60^0 Silo Angles. On the other hand if the Silo Angle is increased for more than 80^0, height of the Silo will be increased drastically and it is not possible design and maintain in a feasible manner. Therefore 50^0-60^0 Silo Angles can be used as the optimum Silo Angle range.

Similarly, according to the requirement, the silo angles and orifice diameters can be determined by using the model and if is necessary the model can be extended.

6.0 Conclusions

The above results show that there exists a variation in the flow rate between the silo angles of 50 to 60 degrees and above 80 degrees. It is not practical to design the silos (hopper) which exceed 80 degrees. Therefore, an optimum discharge rate can be achieved between 50 to 60 degrees, because there is an increase in the discharge rate in between this region for all the minerals which are being tested during the research.

Variations of the flow rate can be observed with respect to the variation of orifice diameter. When the orifice diameter is varied from 15 to 20 mm, nearly a two-fold increase in the flow rate can be observed. When the same factor is varyies above 20mm (20 to 30mm), flow rate increases by ten times. Therefore, designing the orifice diameter within the range between 20 to 30mm coupled with relevant silo angle, an optimum discharge rate could be achieved for a given mineral.

This kind of a model could effectively be used to predict the flow rate beforehand and it enables cost effective applications parallel with minimum wastage of minerals and ultimately excellence of production.

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