FUNDAMENTALS OF IRON ORE, SINTER FEED AND PELLET FEED STORAGE AND HANDLING: WHAT YOU NEED TO KNOW[1]

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Abstract

The production of steel often requires to store and handle iron ore, sinter feed and pellet feed in stockpiles, silos, bins, hoppers, feeders, railcars and chutes. However, these materials may experience flow problems such as arching, ratholing, limited storage capacity, erratic flow, limited flow rate and/or flooding, mainly due to their cohesive nature and poor ability to flow by gravity. The purpose of this paper is to highlight a proven, scientific method that can be utilized to ensure reliable storage, flow and feeding of iron ore, sinter feed and pellet feed in these equipment based on Jenike´s flow-of-solids theory and laboratory testing. Knowledge of the flow properties and characteristics of the material handled provides a design basis to ensure mass flow in hoppers in order to prevent the flow problems mentioned before. This approach should be taken for the proper design of new stockpiles, silos and bins, and also to retrofit existing equipment and/or their corresponding discharge systems. This paper contains a discussion of common flow problems storing and handling products like iron ore, sinter feed and pellet feed, including mass flow technology, testing standards, design procedures, and general recommendations for successful applications.

Key words: Materials handling; Flow properties.

FUNDAMENTOS DE ESTOCAGEM E MANUSEIO DE MINÉRIO DE FERRO, SINTER FEED E PELLET FEED: O QUE VOCÊ PRECISA SABER

Resumo

O processo de produção de aço requer estocagem e manuseio de produtos de minério de ferro como *sinter feed* e *pellet feed* em pilhas, silos, chutes, alimentadores, cabeças móveis, vagões e chutes. Estes materiais podem apresentar problemas ao serem transportados tais como de arqueamento, fluxo preferencial, limitação de capacidade de estocagem, fluxo errático, limitação de taxa de transporte e/ou transbordo e entupimento, principalmente em função de sua natureza coesiva e capacidade de fluir pela força de gravidade. O objetivo deste trabalho é apresentar um método científico comprovado que pode ser utilizado para garantir uma estocagem, transporte e manuseio dos produtos de minério de ferro adequados e confiáveis no tocante ao seu manuseio nos equipamentos. É baseado na teoria de fluxo de sólidos da Jenike e testes de laboratório. O conhecimento das propriedades de fluxo e as características dos materiais manuseados são as premissas do projeto dos equipamentos para garantia de escoamento e para prevenção dos problemas de fluxo mencionados. Esta metodologia deve ser considerada para dimensionamento adequado de novas pilhas de estocagem, silos, chutes e também para repotenciamento de equipamentos e/ou seus respectivos sistemas de descarga. O trabalho discute os problemas de fluxo mais comuns de estocagem e manuseio de produtos de minério de ferro, incluindo tecnologia de fluxo de massa, testes padronizados, procedimentos de dimensionamento e recomendações para aplicações com sucesso.

Palavras-chave: Manuseio de materiais; Propriedades de fluxo.

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1 INTRODUCTION

Vale S.A. is currently one of the leading mining companies in the world with operations in 21 countries. Vale is also the largest brazilian export company, with annual sales of US$ 24 billions in 2010. One of its main export products is iron ore, in the form of sinter feed, pellet feed and pellets.

Vale owns and operates the iron ore mining complex of Carajás located in the state of Pará and the Terminal Marítimo Ponta da Madeira located near São Luis in the state of Maranhão (Figure 1). Approx. 110 Mtpy of iron ore products are currently being transported by railway from the beneficiation plant to the port, unloaded, stored and shipped every year. Presently, Vale is developing several projects to increase the capacity of its Sistema Norte to 240 Mtpy until 2015.

The production of steel often requires to store and handle iron ore, sinter feed and pellet feed in stockpiles, silos, bins, hoppers, feeders and chutes. However, these materials may experience flow problems such as arching, ratholing, limited storage capacity, erratic flow, limited flow rate and/or flooding, mainly due to their cohesive nature and poor ability to flow by gravity. The natural, or mineral, form of iron oxide is widely extracted by mining or quarrying and used commercially to produce steel. Iron ore from the mine or quarry is crushed and sized to meet the process requirements to obtain sinter and pellet feed, which are exported and/or processed locally.

Unfortunately, because of these material's flow behavior during heavy rainy seasons, instances of handling problems occur. Iron ore, whether coarse or fine, dry or wet, sinter feed and pellet feed tend to plug in chutes, stick on conveyors, and cake in stockpiles and silos. The common handling problems may cause many production units to operate inefficiently if they are not properly designed, and often require extra labor to keep the materials flowing through processing, transport and shipping equipment. Due to the materials handling characteristics, Vale has been adopting the strategy of minimazing productivity impacts by characterizing the ore flow and behaviour.

Figure 1. Storage piles at Terminal Marítimo Ponta da Madeira in São Luis, Brazil.

2 BACKGROUND

Bulk materials may or may not gain cohesive strength when handled in stockpiles, silos, bins and hoppers depending on the combination of several factors, such as: height of the pile or silo, percentage and size distribution of fines, moisture content, storage time at rest, and chemical nature of the product. If the material has cohesive strength, like many of the iron ores, sinter feed and pellet feed samples from Vale´s facilities tested by Jenike & Johanson over the years, then problems of arching and/or ratholing may occur - depending on the shape of the hopper, dimensions of the outlet, wall angles, wall liner, and the flow pattern developed by the bulk solid in the stockpile, silo or bin.

2.1 Types of Flow

From the standpoint of flow there are three types of flow patterns that may develop in a bin: funnel flow, mass flow and expanded flow (Figure 2).

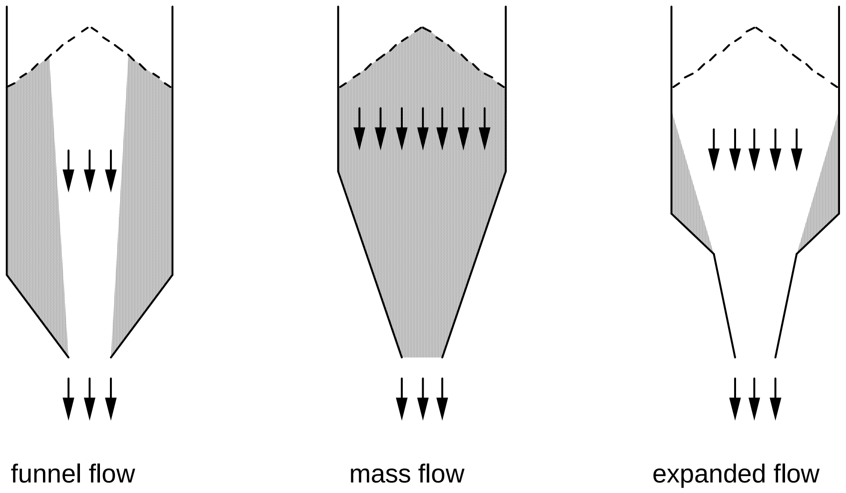

Figure 2. Different types of flow regimes encountered in silos, bins and hoppers.

Funnel flow occurs when the hopper is not sufficiently steep and smooth to force material to slide along the walls or when the outlet is not fully effective. In a funnel flow bin or pile, solids flow toward the outlet through a channel that forms within stagnant solids. With a non free-flowing material, the channel expands upward from the outlet to a diameter that approximates the largest dimension of the effective outlet. When the outlet is fully effective, this dimension is the diameter of the outlet if it is circular, or the diagonal if it is square or slotted (rectangular). Higher within the mass, the flow channel will remain almost vertical, forming a pipe, if its diameter is less than the critical rathole diameter. With a free-flowing material, the flow channel expands at an angle which depends on the effective angle of internal friction of the material. The resulting flow channel is generally circular with a diameter in excess of the outlet diameter or diagonal. When material is withdrawn from a funnel flow silo or stockpile, a flow channel develops right above the outlet and material sloughs off of the top free surface sliding into the flow channel. With sufficient cohesion, sloughing may cease, allowing the channel to empty out completely and form a stable rathole. It is very difficult to break up the stable material around a rathole by external means such as poking or vibration. Depending on the steepness and smoothness of the hopper walls, a bin may or may not empty completely. In general, funnel flow silos and stockpiles are only suitable for coarse, free-flowing or slightly cohesive, non-degrading materials when segregation is not important.

Typically, most iron ore products do not meet the above critera. They contain large amount of fines and high moisture content (often greater than 10%), and can be very cohesive. Lastly, the chemical and metallurgical nature is a major concern with these products. For these reasons, flow-related problems will most likely occur in funnel flow silos; hence, mass flow silos should be used.

Mass flow, on the other hand, occurs when the hopper is sufficiently steep and smooth to force the material to slide along the hopper walls. All the material in a mass flow bin is in motion whenever any is withdrawn. Shallow valleys are not permitted and the outlet must be fully effective. Ratholes cannot form in a mass flow bin, thus eliminating stagnant regions. Mass flow bins are recommended for handling cohesive materials, powders, materials which degrade with time and when segregation needs to be minimized.

Expanded flow is a combination of the two previous flow patterns, in which the lower part of a funnel flow silo or stockpile operates in mass flow. The mass flow hopper should expand the flow channel to a diagonal or diameter equal to or greater than the critical rathole diameter, thus eliminating the likelihood of ratholing. The major advantage of an expanded flow silo is the savings in headroom. Multiple mass flow hoppers can be placed close enough to cause a combined flow channel in excess of the critical rathole diameter. Expanded flow silos and stockpiles are recommended for the storage of large quantities of non-degrading materials, and for modifying existing funnel flow silos to correct problems caused by arching, ratholing and flooding.

2.2 Stockpiles

Due to their economic advantages, gravity reclaim stockpiles are widely used in mining applications to store large quantities of non-degrading bulk solids.(1) The main objective in the design of stockpiles is to maximize the live storage capacity while eliminating ratholing and arching as far as practical given the flow properties of the material handled, the shape and total height of the pile, and the desired discharge rate. For example, Figure 3 shows the model of a prismatic shaped stockpile with 8 reclaim hoppers arranged in-line in the center of the pile. If the material handled is free-flowing (left) the live storage capacity is maximized and, in this case reaches approx. 35% of the total capacity. But if the material handled is cohesive (right) then ratholes form above the outlets and the live storage capacity is drastically reduced, in this case to approx. 7% of the total capacity. Stockpiles are also used to smooth and control the feed of ore onto a belt conveying system while ‘separating’ the mine from the plant, and to feed downstream equipment such as crushers, screens and/or mills.

Figure 3. Scale model of a prismatic stockpile handling different materials.

2.3 Feeders and Gates

Feeders and gates play an important role in the correct operation of stockpiles, bins, silos and hoppers. Feeders are used to control the rate of material discharge from a bin and/or hopper. The rate of material being discharged is most commonly controlled volumetrically (belt, screw or rotary valve) and/or gravimetrically (loss-in-weight system). The main objective in the efficient design of feeders is to obtain a uniform flow of material from the entire bin outlet. This also helps to minimize the loads onto the feeder, to reduce the energy consumption, equipment wear and particle attrition. Hence, if a feeder is used in a bin, it must draw material along the whole length of the outlet area, i.e. the bin and hopper outlets must be fully effective with properly designed interfaces to achieve mass flow.

Using a slotted outlet requires that the feeder capacity increase in the direction of flow. When using a belt feeder, for instance, this increase in capacity can be achieved by using a tapered interface (Figure 4).

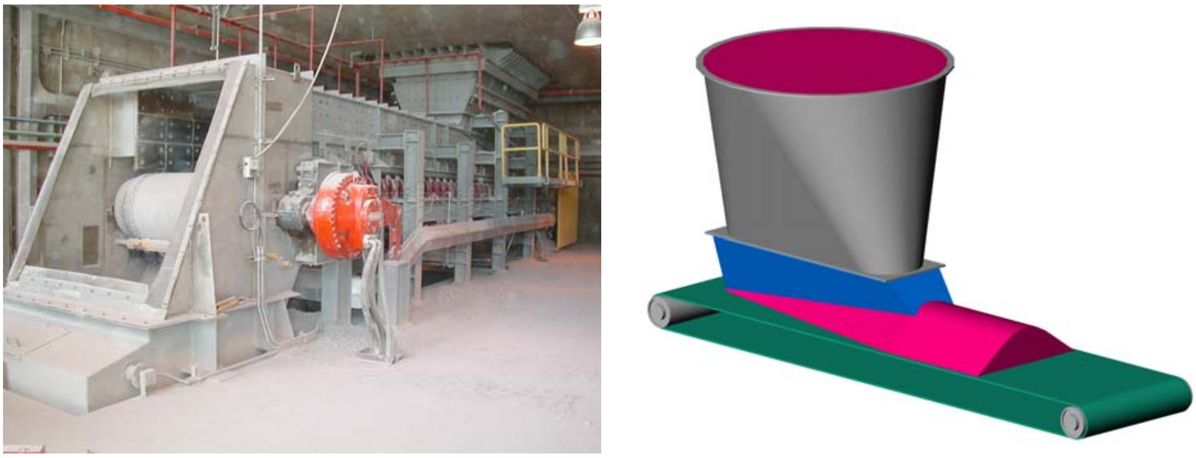

Figure 4. Belt feeder and details of a mass flow interface.

The increasing capacity along the length is achieved by the increase in height and width of the interface above the belt.(2) We recommend and favor the use of variable speed, troughed belt feeders with 20° picking table idlers instead of flat belts to reduce belt sag between idlers and to minimize spillage of material. Sligthly diverging skirts are usually used to achieve the necessary bed depth of material.

Screw conveyors are often used to feed material from elongated hopper outlets. Standard screw conveyors, when used as feeders, withdraw material only from one end of the slotted hopper outlet (Figure 5). By design, the constant pitch screw does not have an increase in volumetric capacity along the length of the hopper outlet in the direction of discharge; hence, material feeds into the first pitch section at the back of the screw which conveys material to the next pitch and so forth. Since material cannot flow from the hopper outlet into the remaining sections, a narrow flow channel forms inside the hopper. This flow channel converts even a mass flow silo to funnel flow, which can lead to ratholing, flooding, or even segregation problems. The power to operate the conveyor also increases because of inefficiency and stagnant material in the hopper resting on top of the screw.

In addition to ensuring that the hopper walls are low enough in friction and steep enough for material to flow along them and that the outlet is large enough to prevent arching, mass flow requires that material flow takes place through the entire cross-sectional area of the outlet.

In contrast, a mass flow screw feeder draws material uniformly from the entire cross-sectional area of the hopper outlet. The mass flow screw feeder is designed to provide a uniform increase in capacity along its length. This is usually accomplished with a combination of a tapered shaft with constant pitch flighting plus constant diameter shaft section with increasing pitch flighting.(3)

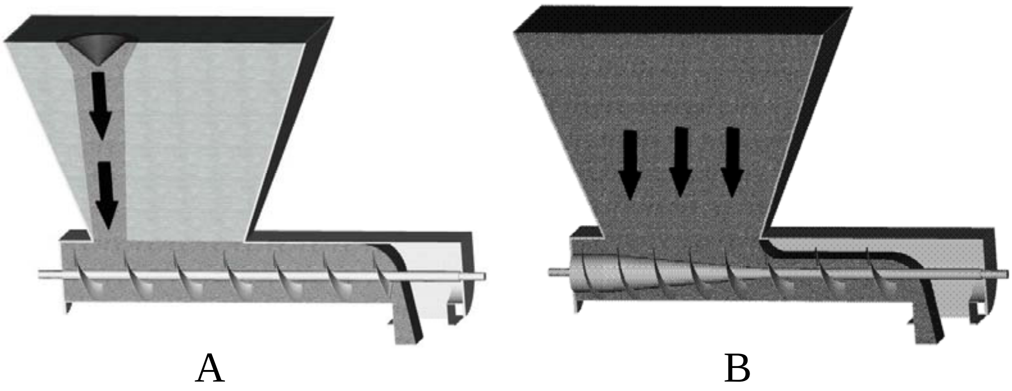

Figure 5. (a) Hopper with screw conveyor; (b) and mass flow screw feeder.

If a gate like an emergency slide or spile bar shutoff ‘pin gate’ valve is used below a mass flow hopper, the gate must be operated either fully open or fully closed. It is critical that the blade or spile bars do not protrude into the material flow during normal operation. A partially live outlet, such as due to a partially open slide gate, will result in funnel flow regardless of the hopper design.

2.4 Chutes

Chutes are used to direct the flow of bulk solids, whereas silos and hoppers are used to store bulk solids. Therefore, chutes should be designed differently than silos and hoppers. Unfortunately, chutes often fail to perform reliably, frequently exhibiting problems such as plugging, spillage, wear, dust generation and/or particle attrition.

A chute must be sufficiently steep and smooth to permit sliding and clean-off of the most frictional bulk solid that it handles.(4) This is particularly important at impact points such as after a free-fall or where the flow of material changes direction. However, chutes should not be steeper than necessary so as to keep material velocities and wear to a minimum.

2.5 Flow Aids

Gravity alone is usually sufficient to cause most materials to flow reliably. If the silo or bin has been designed correctly, based on the flow properties of the material and using well-proven design procedures and calculations, flow aid devices won’t be needed.

However, mechanical flow aids, such as vibrators, air cannons, etc., can be helpful at times to get some materials flowing. But they are usually ineffective with cohesive, frictional materials like iron ore, sinter feed and pellet feed. Often vibrators tend to pack material in a hopper and create worse and more frequent arching and ratholing problems. Air cannons may be effective in initiating flow of material after the material has remained at rest for a period of time; however, if the material is cohesive even during continuous flow, then air cannons are usually not a good solution because they must be fired repeatedly to maintain flow. Also, even though air cannons may be effective in breaking arches which form after storage at rest, they are usually ineffective in breaking up ratholes that form in funnel flow silos.

3 FLOW PROBLEMS

The most common flow problems that may occur in an improperly designed stockpile, silo, bin or hopper when handling materials such as iron ore, sinter feed and pellet feed, include arching, ratholing, erratic flow, limited flow rate, and excessive wear. Other potential flow problems could be segregation, flooding, dust generation, vibrations, etc.

Arching occurs when an obstruction in the shape of a "bridge" forms above the outlet of a hopper and prevents any further material discharge, either by an interlocking arch or by a cohesive arch. An interlocking arch occurs when the particles mechanically lock to form the obstruction because they are too large compared to the outlet size of the hopper. A cohesive arch occurs when particles pack together to form an obstruction, as shown schematically in Figure 6.

Ratholing, which is common in funnel flow silos and stockpiles handling cohesive materials such as iron ore, sinter feed and pellet feed, occurs when proper design is not used to avoid that material surrounding a flow channel develops sufficient cohesive strength to remain stagnant as the flow channel empties. For example, Figure 7 shows a typical drawdown test performed in a slice 2D plane model with sinter feed and pellet feed, both at 10% moisture. This simple test illustrates the repose and final drawdown angles that may occur in a flat-bottom stockpile and/or silo. Clearly, the materials tested show considerable strength and a high tendency to rathole if handled in a flat-bottom silo.

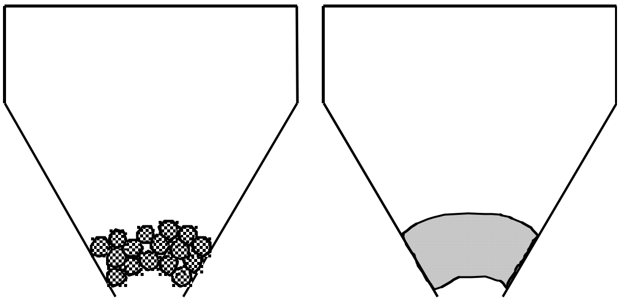

Figure 6. Interlocking (left) and cohesive arching (right).

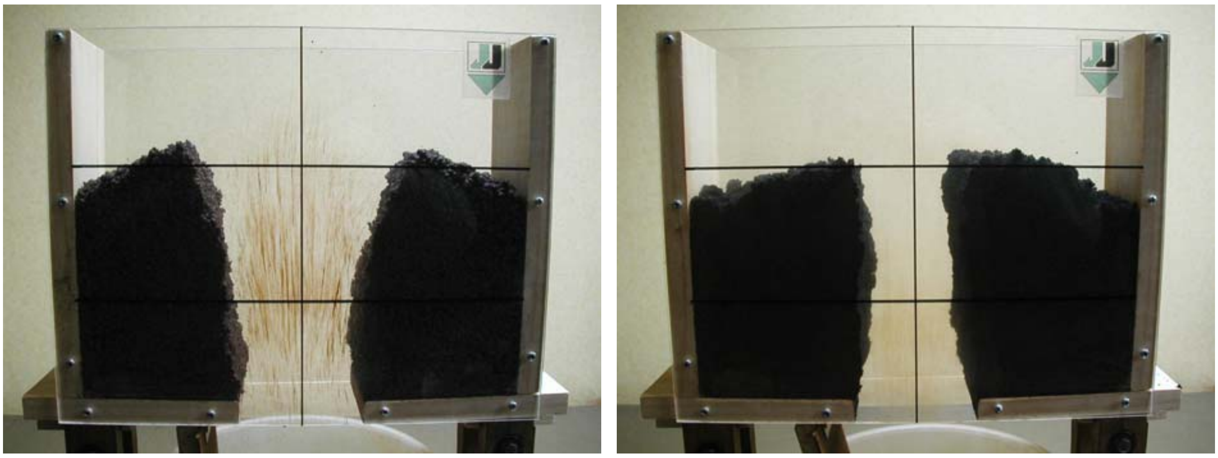

Figure 7. Ratholing of sinter feed (left) and pellet feed (right) tested at 10% moisture.

Erratic flow is the result of an obstruction alternating between an arch and a rathole causing feed fluctuations and vibrations. A rathole may fail due to an external force, such as ambient plant vibrations, vibrations created by a passing train, or vibrations from a flow aid device such as an air cannon, vibrator, etc. While some material discharges as the rathole collapses, falling material often gets compacted over the outlet and forms an arch. This arch may break due to a similar external force, and material flow resumes until the flow channel is emptied and a rathole forms again. Collapsing ratholes and arches can cause silos to shake or vibrate. They can also impose significant dynamic loads that can result in structural failures of hoppers, feeders or silo supports. In addition, non-symmetric flow channels alter the loading on the cylinder walls and can lead to silo wrinkling or buckling.

4 FLOW PROPERTY TESTS

Testing provides the best method to characterize a material and its handling properties for proper equipment and systems selection, design and dimensioning. To know how a bulk material will behave under specific conditions and to provide a basis for designing storage and handling equipment such as stockpiles, silos, bins, hoppers, reclaim feeders, chutes, railcars and others, the flow properties and cohesive strength as a function of moisture content, storage time at rest and consolidating pressure of the materials must be determined. About five decades ago, Dr. Andrew Jenike(5) proposed a flow-of-solids theory to properly design silos, bins and hoppers. This theory is based on the flow properties of the material handled, which should be determined in a laboratory at the expected operating conditions to be encountered in the plant.

Materials like iron ore, sinter feed and pellet feed can present different degrees of undesirable handling characteristics, like being cohesive, frictional, compressible, and relatively impermeable. As a result they are difficult to handle in most bulk solids systems, being prone to arching, ratholing, flooding and wearing.

In general, the following characteristics and flow properties are required for properly designing a storage and handling system:

- particle size and size distribution;
- particle density;
- cohesive strength;
- compressibility;
- wall and chute friction;
- wear.

According to our experience, the flow properties of most bulk solids are affected by the following parameters and must be determined for the range of operating conditions expected, including upset conditions:

- maximum particle size and content of fines;
- moisture content;
- storage time at rest and under pressure;
- consolidating pressure (i.e. height of the pile or bin);
- temperature and relative humidity;
- presence of contaminants;
- chemical nature of the material.

Any tests run on the material to be handled should “duplicate” the conditions to be encountered in the field. Otherwise, test results may prove to be useless. For example, instantaneous and time (e.g. 24, 48, 72 hours or more) flow property tests should be performed on the minus ¼” fraction[1] (100% - 6.3 mm) of representative samples of the iron ore to be handled in a storage and handling system and at different moisture contents, to determine how sensitive this material is to an increase in water content. To accommodate for variations in material, tests should be conducted on multiple samples obtained from various sources or mines and at various times. Plant operating

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[1] From a flow of solids viewpoint, “fines” are defined here as the fraction passing a ¼” ASTM E-11-87 standard sieve, i.e. 6.3 mm opening.

experience and/or geological information can be valuable in making such determinations.

4.1 Strength

Instantaneous and time flow function tests (standard ASTM D 6128)(6) should be performed to determine the cohesive strength of the material and the minimum dimensions of hopper outlets to prevent arching and ratholing. Laboratory tests are conducted applying a consolidating force to the material in a test cell, and measuring the force required to shear the material. The flow function is namely the cohesive strength vs. consolidating pressure.

As mentioned, the formation of stable ratholes in funnel flow bins and/or stockpiles leads to flow stoppages and loss of live storage capacity. To avoid the problem of ratholing and to ensure reliable flow, mass flow hoppers should be used to expand the flow channel to a diameter greater than the critical rathole diameter. The critical rathole diameter is a function of the cohesive strength of the material, which in turn increases with consolidation pressure (effective head). Thus, the higher the storage bin or pile, the greater the critical rathole diameter and the larger the plan dimensions of the mass flow hopper required to prevent rathole formation. Ideally, the upper diagonal of the hopper should be larger than the critical rathole diameter.

4.2 Compressibility

Compressibility tests (standard ASTM D 6683)(7) should be performed to determine the variation of the bulk density of the material as a function of consolidating pressure in a bin and/or a silo (effective head). The bulk density of the material handled is required for estimating bin volume and wall pressures, feeder loads, minimum outlet dimensions, etc.

4.3 Wall Friction

Instantaneous and time wall friction tests (standard ASTM D 6128)(6) should be performed to determine the smoothness and steepness of the hopper walls required to force flow along them, i.e. to obtain mass flow, as will be explained later. A small sample of material (bulk solid) is placed in a test cell and pushed along a wall surface. Various normal forces are applied to the cover, and the shear force is measured, similar to the flow friction test. From a plot of the shear force versus the applied normal force, the wall friction angle, ϕ', can be measured. This angle is another way of expressing the coefficient of sliding friction ($\mu = \tan \phi'$) used in wall pressure calculations.

Wall friction tests should be run onto different types of liners like carbon steel, stainless steel with #2B or #1 mill finish, abrasion resistant steel liners (e.g. T-1, T-500 or Astralloy-V®), polyethylene and/or u.h.m.w.p. liners (e.g. Tivar-88®) to find out the wall material with the best wall friction characteristics for the iron ore, sinter feed or pellet feed to slide on.

4.4 Chute Tests

Similarly, chute sliding tests should be performed onto different types of liners to determine the minimum slope of a flat, non-converging plane surface to keep flow of material after impact, as a function of impact pressure, flowrate and free-fall heights to occur in the plant. Usually, chute friction tests for iron ore, sinter feed and pellet feed are run onto the same types of liners used for wall friction tests. To prevent chute plugging problems and properly design transfer points for reliable flow, the first step is to test and determine the main characteristics and flow properties of the material to be handled.

4.5 Wear

A certain amount of wear takes place in a mass flow silo when handling abrasive materials, such as iron ore, sinter feed or pellet feed, due to particles sliding along hopper walls. Often it is important to estimate the amount of abrasive wear that will take place, in making decisions between various liners and the required thickness of a particular liner or wall material for a given lifetime.
A wear tester developed by Jenike & Johanson can be used to estimate the amount of abrasive wear in a particular silo due to solids flow.(8) These tests are conducted by exposing a sample of wall surface to material flow at pre-determined flow rates and pressures, and measuring the resulting wear. From this information, a dimensionless wear ratio is computed, which in turn is used to predict the amount of wear in a given silo as a function of the amount of solids flowing through it.

5 ACHIEVING MASS FLOW

The two main considerations in the design of mass flow hoppers are: the smoothness and steepness of hopper walls (θC and θP shown in Figure 8) required to force flow along the walls, and the size of the outlet (BC and BP) required to prevent arching and to achieve the required flow rate.

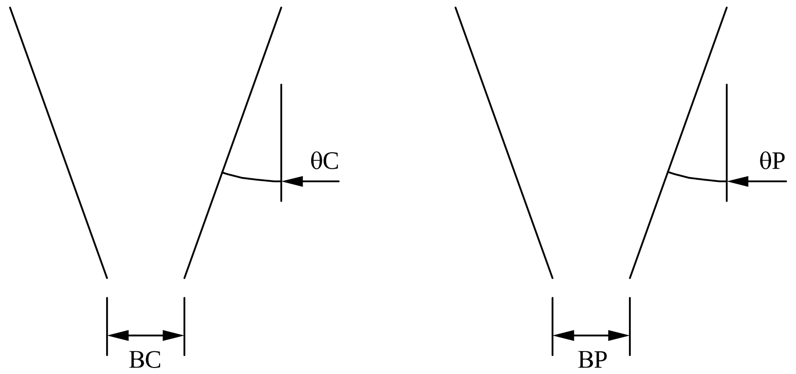

Figure 8. Conical (left) and wedge shaped or transition (right) mass flow hoppers.

5.1 How Steep and Smooth must a Hopper Surface be to achieve Mass Flow?

The answer depends on the friction that develops between the bulk solid and the hopper surface, i.e. wall friction as described before. In order to achieve mass flow the sloping hopper walls must be steep enough and low enough in friction for the particles to slide along them. In general, a number of factors can affect wall friction for a given bulk solid, such as:

- wall material: generally, smoother wall surfaces result in lower wall friction (there are exceptions); hence, shallower angles can be used for mass flow;
- bulk solid condition: variations in moisture content, material composition, and particle size usually affect wall friction;
- time at rest: some materials adhere to a wall surface if left at rest in a hopper. Wall friction tests should be performed to measure the increase in wall friction angles (if any) due to storage at rest. If adhesion takes place, steeper hopper angles are required;
- corrosion: wall materials that corrode with time almost always become more frictional;
- abrasive wear: often, abrasive wear results in smoother wall surfaces; therefore, designs based on an unpolished surface are usually conservative. However, abrasive wear can occasionally result in a more frictional surface, which can disrupt mass flow. When handling abrasive materials, wear tests should be performed to determine the effect on wall friction, as well as calculate the amount of wear expected.

Based on wall friction angles measured in the laboratory, limiting hopper angles for mass flow can be determined using the flow-of-solids theory developed by Dr. Andrew Jenike.(5) Figure 9 shows examples of design charts for mass flow in conical and wedge shaped or transition hoppers for a given material. Note that both angles θC and θP are measured from the vertical.

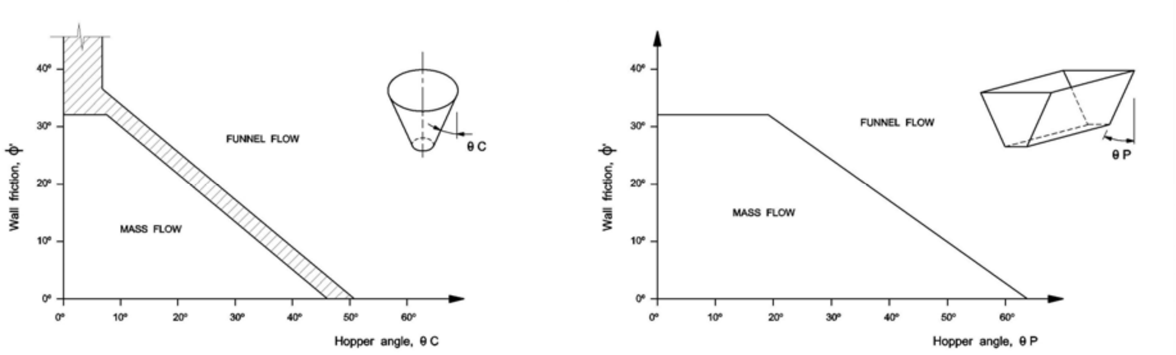

Figure 9. Design charts for mass flow in conical and wedge shaped hoppers.(7)

It is important to point out that in plane flow (wedge or transition hoppers), mass flow hopper angle requirements are generally 10° to 12° less steep than for conical hoppers. It also turns out that the plane flow geometry is more robust from a design standpoint, capable of handling wider variations in material and surface characteristics. In the case of pyramidal hoppers, the valley angles created between two adjacent sloping walls need to be equal or steeper than θC in order to obtain mass flow. Clearly, a wedge shaped hopper with vertical end walls requires much less headroom and becomes a much more practical design for mass flow.

5.2 Hopper Outlet Size

Having selected the hopper wall liner and side slopes to achieve mass flow, the second consideration is the correct sizing of the hopper outlet, which must be sized to:

- prevent cohesive arch formation;
- prevent arching due to large particle interlocking;
- achieve the desired discharge flow rate.

The first type of arching, namely due to the cohesive nature of a material, can be overcome by measuring its strength in the laboratory, i.e. the flow function as described before. The minimum outlet sizes for mass flow and funnel flow bins can be determined using the flow-of-solids theory developed by Jenike.(5) Typically, the minimum outlet diameter to prevent arching over a circular outlet is roughly twice the minimum width required for a slotted outlet. A number of factors that affect the minimum outlet required to prevent cohesive arching include:

- particle size: generally as particle size decreases, cohesive strength increases requiring larger outlets to prevent arching. Also, materials with wider ranges of particle size distribution are less flowable;
- moisture content: increased moisture content generally results in an increase in cohesive strength, with the maximum typically occurring between 70% and 90% of saturation moisture. At moistures higher than these values, bulk solids tend to become slurry-like and their cohesive strength decreases;
- time at rest: similar to wall friction, some materials exhibit an increase in their cohesive strength if left at rest for some period of time. Cohesive strength can be measured in the laboratory using a direct shear tester simulating storage time at rest.

To prevent arching due to large particle interlocking in a conical hopper, the diameter of a circular opening BC must be at least 6 times the largest particle size. Similarly, to prevent arching due to large particle interlocking in a wedge shaped hopper, the width of a slotted opening BP must be at least 3 times the largest particle size while the length must be at least 3 times the width BP. For example, assuming a maximum particle size of a crushed iron ore to be 4" (i.e. 100% - 100 mm), the width recommended for a slotted outlet of a wedge shaped hopper should be 300 mm or larger, and the length must be at least 900 mm.

Finally, hopper outlets should be sized also to achieve the required flow rate with a proper interface between the bin and the feeder, as explained before, and also to match downstream equipment in the case of retrofitting an existing bin.

6 CONCLUDING REMARKS

In summary, this paper highlights the application of a bulk solids flow theory proposed originally by Jenike to design or retrofit storage bins and feeding systems for iron ore products or other bulk solids. Even though this theory has been published and available for more than 45 years, it is still common to see flow problems in stockpiles, silos, bins, hoppers, feeders, railcars and chutes.

The first step is to know the main characteristics and flow properties of the iron ore, sinter feed and/or pellet feed to be stored and handled, by properly testing representative samples of the material at the specific conditions to be encountered in the plant. Based on these test results, flow patterns can be predicted and flow problems can be avoided. Hopper angles for mass flow can be determined by measuring the wall friction angles, and the minimum outlet size to prevent cohesive arching can be calculated by determining the cohesive strength of a material. These are two of the main flow related requirements for designing a mass flow silo

Over the years, Jenike & Johanson engineers have worked with Vale engineers and with other clients on a number of projects including storing and handling different types of iron ore, coarse and fine, dry or wet, sinter feed and pellet feed. Not only designing new equipment such as stockpiles, silos, bins, hoppers, feeders, railcars and chutes but also retrofitting existing equipment to solve flow problems and ensure reliable flow.

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