Flow of Solids from Bins and Hoppers¹ – Benefits of TIVAR® 88 Lining Systems

> BULK SOLIDS FLOW

Whether designing a new storage bin, bunker or silo or modifying an existing structure to improve flow performance, the engineer must have knowledge of the bulk material characteristics being handled and understand flow of solids theories. Traditionally, 304-2B stainless steel has been the hopper wall material chosen by the engineer for new construction because of the long history of use. To solve flow problems in existing structures, the typical “fix” has been the use of loud, noisy flow promotion devices. People think that if you beat on the structure or shake it you will get flow. However, these remedies often cause as many problems as they solve, and in a number of cases, flow problems continue even with the use of such “active” methods.

TIVAR® 88, an alternative to “hopper beating”, is a lining material that has been proven to offer better flow performance than 304-2B stainless steel in a variety of different applications. In many retrofit situations, our experience has been that TIVAR® 88 is installed over the top of existing 304-2B stainless steel liners because the stainless steel lined hoppers were not providing satisfactory or acceptable performance. In new construction, engineers are able to design hoppers with shallower wall angles and still achieve mass flow by using TIVAR® 88 as the wall material because of its low surface friction.

Although traditional may be comfortable, when it comes to flow promotion methods, traditional may not be optimal in terms of performance. In fact, there are many new tested and proven methods available today that successfully achieve reliable solids flow. In many cases, these methods will outperform the traditional methods. But no matter what method is considered, it is imperative that engineers design with a thorough understanding of a bulk solids’ characteristics and knowledge about vastly improved flow promotion methods.

For clarification, a bulk solid will be defined as numerous wet or dry solid particles ranging from fine powder to more than several inches in size that are being handled in bulk form. These materials are stored in vessels that are commonly referred to as a bin, bunker, silo, process vessel or elevator. The vertical portion of the vessel is the cylinder and the converging portion is the hopper, as shown in Fig.1.

![Figure 1: Storage vessel terminology](image1)

Figure 1: Storage vessel terminology

![Figure 2: No flow](image2)

Figure 2: No flow

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**PROBLEMS ASSOCIATED WITH BULK SOLIDS FLOW**

1.) **No Flow**

   A stable arch (bridge) or rathole forms over the hopper outlet as shown in Fig. 2. The arch is strong enough to support the weight of material above it and it must be broken by some method in order to induce flow again. Generally, sledgehammers, air lances and air blasters are used to break the arch. Vibrators have a tendency to strengthen the arch because, in most cases, they promote compaction.

   A rathole is formed when a cylindrical flow channel develops in the center of the bin and the remaining material is stationary along the hopper walls. This generally occurs when the walls are not steep and smooth enough.

2.) **Erratic Flow**

   Alternating formation and collapse of arches and ratholes (Fig. 3) result in fluctuating discharge. This causes thumping and vibrations that can damage or destroy the integrity of a bin, leading to structural failure and potential personnel injuries or deaths.

3.) **Flushing or Flooding**

   Fine powders become aerated and discharge uncontrollably from the bin, behaving like a liquid, as shown in Fig. 4. This can happen when a rathole collapses allowing the solids to fall into the open channel under pressure.

4.) **Limited Discharge Rate**

   The flow from the hopper outlet is not adequate for process requirements.

5.) **Segregation**

   Solid particles have a tendency to separate during the filling of a bin, as shown in Fig. 5. The finer particles will be predominately in the center of the bin and the larger particles will roll and collect against the bin wall. If flow does not occur along the bin wall during discharge, the finer particles discharge first and the coarse particles last.

**Results of Flow Problems**

These very common flow problems will have a variety of effects on a particular process that can result in quality problems, lost production, fire, product spoilage, structural damage, personnel injuries and wasted time and money. Reduced storage capacity, as shown in Fig. 6, results from the formation of stable ratholes. The bulk solid will cake and cement itself to the bin walls if it is not cleaned from time to time. The severity of these stagnant or “dead” regions will vary according to the material being handled. For example, in the food industry, the bulk solid will spoil, encouraging insect infestation. In coal handling industries, the stagnant coal is highly susceptible to spontaneous combustion the longer the coal is allowed to remain in the bin.

Spontaneous combustion gets a lot of attention in the power industry where large volumes of coal are stored in the silos and bunkers that feed the boilers. Many power companies are plagued with fire problems that can eventually lead to explosions if dusting occurs while they are charging a bin.

In large silos, vibration and thumping can occur during discharge resulting in structural fatigue and collapse. There are documented cases where the entire silo area was declared “off limits” to individuals during the time of discharge for fear that a fatality could occur if the structure collapsed. Segregation issues make quality control nearly impossible, greatly impacting the bottom line in industries where consistency is required from batch to batch.

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Three types of flow patterns have been identified: funnel flow, mass flow, and expanded flow. All have profoundly different characteristics that must be understood in order to address bulk solids flow challenges.

1.) Funnel Flow

This pattern is ideal for free flowing, non-segregating bulk materials. A funnel flow pattern is not recommended for bulk materials that are cohesive or segregate. A cylindrical flow channel develops in the center of the bin above the outlet while the material against the bin walls remains stationary, as shown in Fig. 7. Once the center portion is withdrawn, the material along the walls begins to flow until it is empty. This flow pattern can be referred to as first-in, last-out. If a cohesive bulk solid is handled in this fashion a rathole may develop.

If the hopper walls are not steep enough or if a rough wall condition exists a funnel flow pattern will develop. This is the situation in many coal bunkers today, especially if the coal has a high moisture content or if it contains a lot of fines. When there is no flow along the hopper walls, stagnation results. If the stagnant areas are allowed to remain for extended periods of time, quality may be compromised and spontaneous combustion can occur when handling coal.

The pyramidal shaped hopper, as shown in Fig. 8, is a common design that promotes funnel flow. The walls are generally shallow to keep the overall height of the bin low, but more importantly, the valley angles are shallower than the adjoining walls. Most non-free-flowing solids will begin to pack or cake and then remain stagnant in the valley angle region.

The use of TIVAR® 88 in a funnel flow bin will provide the low surface friction necessary to promote flow along the walls after the center portion empties. Unlike many steels, TIVAR® 88 has the corrosion resistance necessary to prevent a rough wall condition from occurring due to corrosion. Therefore, it enhances the performance of a funnel flow bin by assisting in complete clean-out.

2.) Mass Flow

This is a first-in, first-out flow pattern in which all of the bulk solid is in motion when any of it is withdrawn (Fig. 9). Ratholes are eliminated, because there is flow along the walls and segregation is minimized because the segregated material in the bin remixes as the bin empties. This flow pattern is ideal for cohesive solids and those that degrade with time. Stagnant or “dead regions” are eliminated, thereby minimizing the possibilities of spontaneous combustion. See Fig. 10 for examples of mass flow bins.

It is possible to achieve mass flow in a funnel flow bin by lining the hopper walls with TIVAR® 88. The low surface friction of TIVAR® 88 promotes flow along the walls as long as the walls are steep enough for the bulk solid being handled. To quantify the bulk solid’s characteristics, flow properties should be run to determine if mass flow can be achieved by lining the hopper walls. The Jenike Shear Tester® (ASTM D 6128-97) is a device commonly used for this testing.

Experience has shown that using TIVAR® 88 as a liner in a new mass flow bin is economically sound when the hopper walls can be designed
Many bins and hoppers are designed based on the angle of repose of a bulk material, available space and/or process requirements without consideration given for the bulk solids’ flowability characteristics. Unfortunately, this results in many poorly designed systems that do not provide uninterrupted, reliable flow.

In order to quantify the properties of a solid to arrive at design parameters, flowability tests should be conducted using actual samples of the bulk solid. One proven method is the Jenike Shear Tester® (ASTM D 6128-97), which allows the technician to measure shear forces of the bulk solid sliding against itself (internal friction) and the bulk solid sliding against the proposed wall material Fig. 13. This is also a useful tool in determining the critical arching and ratholing dimensions based on the cohesive strength of the solid (Fig.13).

In a basic sense, the tester is comprised of two circular steel rings approximately 4” in diameter that are machined to slide against each other, a plotter or recording device and a pin that applies the shear force. The rings are placed on top of each other, filled with a bulk solid and an appropriate weight is placed on top of the solid to correspond to the pressures expected in the bin. The shearing pin then applies pressure to the top ring while the bottom is held stationary to shear the bulk solid against itself. The amount of force required to shear the consolidated sample is recorded. A similar procedure is done to measure the force required to shear the consolidated sample against various wall materials and again, the force is recorded. The recorded data are used in calculations to arrive at wall angles, outlet dimensions, etc.

The world’s leading flow consultants are available to conduct flowability tests on any bulk solid and will provide clients with a series of design options that include bin geometry, discharge feeder suggestions, wall materials that promote flow, finite element analysis and other related services. Contact Poly Hi Solidur or see the inset box at the end of this paper to find a consultant near you.

In addition to flowability testing, three other factors impacting the flow characteristics of a bulk solid must be taken into consideration – moisture content, temperature and storage time at rest.

3.) Expanded Flow

This is a combination of both mass flow and funnel flow. The upper portion is designed for funnel flow and the lower portion is designed for mass flow, in Fig. 11.
DESIGN CRITERIA (CONT.)

Moisture content modifies the properties of a solid affecting its cohesive strength and arching dimensions. It will also affect the frictional properties of a solid. In general, as the moisture increases, the flowability decreases. Once saturation is reached, if the solid is at rest for some period of time the water drains from the solid leaving it at its minimum flowability level.

Temperature will affect the flow properties of a solid, especially freezing and thawing that takes place around 32° F (0° C). At higher temperatures there is a tendency for increased adhesion as the bulk solid becomes less free flowing.

Storage time at rest will cause some solids to consolidate or compact. Some will gain moisture and some will lose moisture as the moisture migrates to the bin walls. Moisture migration to the bin walls can cause adhesion to take place. If the storage time is extended and the material gains enough strength to arch, some type of mechanical method is required to induce flow. Once flow is induced in a mass flow hopper, the gravity flow will continue. It is critical, however, for the hopper walls to be steep enough and have a low surface friction. The surface friction of TIVAR® 88 is one of the lowest available, which is the reason it is chosen as the hopper wall material in many applications.

TIVAR® VS. OTHER WALL MATERIALS

Poly Hi Solidur maintains a comprehensive database of information on the performance of TIVAR® 88 when used with a variety of bulk materials compared to the performance of other wall materials. This information has been accumulated during the more than 30 years Poly Hi Solidur has been in the bulk material handling business. From this data, we are able to provide some examples of the results. It is important to note that these examples are not to be used as design criteria. We recommend that flow property testing be conducted on each bulk material in order to derive design data. In most cases, TIVAR® 88 outperforms 304-2B stainless steel, a fact which has been documented in many full-scale applications. Situations that we see quite frequently are flow problems in a bin that has a hopper section lined with a type 304 stainless steel with a 2B finish. Installing TIVAR® 88 over the top of the stainless steel has been a very effective solution for those flow problems.

Key to TIVAR® 88’s success in promoting bulk material flow along hopper walls is its low surface friction. It should be noted, however, that smoothness of surface and low surface friction are not the same characteristic. For example, when tested using Australian brown coal (ignite) with 56% moisture content, TIVAR® 88 exhibits a very low wall friction angle, while the 304-2B stainless steel is entirely unsuitable because it exhibits a high friction despite the smoothness of its surface.

As another example, consider sub-bituminous coal with 35.3% moisture from the Powder River Basin in Wyoming (Table 1). Mass flow can be achieved in a conical TIVAR® 88-lined hopper that has a 61° sloping wall from the horizontal and a 2-foot diameter outlet. However, for mass flow...
to occur with a 304-2B stainless steel-lined conical hopper, the sloping walls must be 74° from the horizontal with a 2-foot diameter outlet.

Consider the same sub-bituminous coal that has been allowed to remain in the hopper for 65 hours. Note how the wall angles have significantly increased. It is important that designers understand that each bulk material should be tested for its flow properties using all possible scenarios to arrive at this type of design criteria. It is not possible to use general criteria because all bulk solids behave differently. For example, coal with a moisture content of 33.4% will behave differently than coal with a moisture content of 35.3%.

There is an economic benefit to designing bins with shallower wall angles to lower the overall height of the structure. Fig. 14 shows the overall height relationship of two different bins, both having a 440-ton storage capacity handling a solid with a bulk density of 50 lbs./ft.³. One bin has a 45° hopper and the other has a 70° hopper.

<table>
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<th>Wall Material</th>
<th>Hours of storage at rest</th>
<th>Temp. (F)</th>
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<th>33.4% moisture content</th>
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<td>61°</td>
<td>59°</td>
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<tr>
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<td>76°</td>
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<tr>
<td>304-2B S.S.</td>
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<td>76°</td>
<td>N/A</td>
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</table>

Table 1: Sub-bituminous coal from Powder River Basin, Wyoming

**Figure 14:** Height relationship between 45° and 70° hoppers

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SUMMARY

On numerous occasions, coal-fired power plants experience flow problems in their coal silos even when hopper sections are designed with 70° cones and are lined with 304 stainless steel with a 2B finish. Many cases of “thumping” or tremendous vibration during discharge and arching occur because the hopper wall is not steep enough or the wall friction is too high.

One theory states the problem will alleviate itself as the flowing coal polishes the stainless steel surface. Unfortunately, this does not always happen. To achieve smooth, uninterrupted flow and eliminate the problems within the hopper, a TIVAR® 88 liner is placed on top of the stainless steel, creating a very low surface friction environment which allows the coal to flow smoothly on 70° hopper walls.

These coal-handling problems are particularly apparent when handling sub-bituminous and lignite coals due to the combination of finer particle sizes and higher moisture levels.

Using partial TIVAR® 88 hopper linings within a silo, while improving mass flow, may not be sufficient to create mass flow in all circumstances.

As noted previously, coal flowability characteristics are different for coal mined in different locations. Once all the bulk material flowability criteria has been determined, it is often necessary to line the entire hopper section with TIVAR® 88 to promote mass flow. Flowability tests can be run on the coal using the Jenike Shear Tester® (ASTM D 6128-97) to determine flowability and to allow you to evaluate the performance of a hopper liner in specific applications.

REFERENCES

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