

## Coal Flowability Tests Indicate TIVAR<sup>®</sup> 88 Outperforms Stainless Steel

Whether designing a new storage bin, bunker or silo, or modifying an existing hopper to improve flow performance, the engineer must have knowledge of the bulk material characteristics being handled and understand the flow of solids theories.

Traditionally, 304-2B stainless steel has been the hopper wall material chosen by the engineer for new construction because of its long history of use. To solve flow problems in existing hoppers, the typical “fix” has been the use of loud, noisy flow promotion devices. The theory is, that if you beat on the hopper or shake it, you will achieve mass flow. However, in many

cases, these remedies are not the answer.

TIVAR<sup>®</sup> 88, a hopper lining material recognized worldwide for its low coefficient of friction, offers an alternative solution – one that exhibits better flow promotion properties and performance than 304-2B stainless steel in many applications. In many retrofit situations, Poly Hi Solidur’s experience has been that TIVAR<sup>®</sup> 88 is installed on top of existing 304-2B stainless steel liners because the stainless steel-lined hoppers were not providing satisfactory or acceptable performance.

For new construction applications, engineers are able to design hoppers

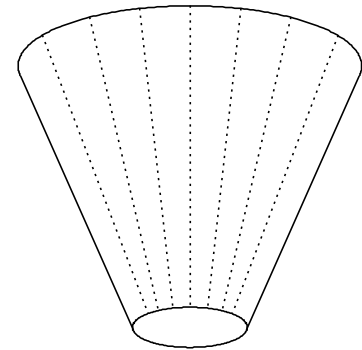
with shallower wall angles and still achieve mass flow by using TIVAR<sup>®</sup> 88 as the wall material due to its low surface friction<sup>1</sup>.

As part of an effort to show engineers some performance comparisons of TIVAR<sup>®</sup> 88 versus 304-2B stainless steel, Poly Hi Solidur contracted the services of Jenike & Johanson, Inc., of Westford, Mass., to provide quantitative independent test results. The data presented are not to be used as design criteria; it is for information purposes only.

In order to quantify the properties of a solid to arrive at design parameters, flowability tests should be conducted

### Wall Angle for Conical Hoppers

Coal Sample Identification	Wall Material				Hours at rest
	Time at rest = 0 storage hours		After storage time at rest (hours at right)		
	TIVAR <sup>®</sup> 88	304-2B SS	TIVAR <sup>®</sup> 88	304-2B SS	
Lignite	69	*	77**	*	72
Western (sub-bitum.)	61	74	66	76	72
Kentucky, -1/4"	61	79	64	79	20
Lignite, pulverized	64	66	***	***	
Lignite, raw	58	77	60	80	72
“Waste” coal	63	66	65	68	24
Minus 1/4"	64	71	73	72	67
Eastern (bitum.)	65	68	65	86	1
Coal, 8% moisture	63	73	64	73	66
Coal, 17% moisture	71	76	75	76	66
Midwestern	64	71	66	84	26
Midwestern	69	74	70	*	26
95% coal, 5% coke (sub-bitum./PRB)	65	81	77	81	65



Conical shaped hopper design

**Table 1:** Typical wall friction data from various types of coal found in the U.S. These values represent the hopper angle (degrees from the horizontal) required to achieve mass flow in a conical-shaped hopper having a 2ft. (610mm) diameter outlet dimension.

<sup>1</sup>Flow along the walls of either a cone or plane flow hopper is questionable.

\*\*Conical hopper angles steeper than about 75° usually require special design considerations such as inserts.

\*\*\*No tests were run.

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using actual samples of the bulk solid. One proven method is the Jenike Shear Tester<sup>2</sup> (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. The recorded data are used in calculations to arrive at hopper wall angles required for mass flow,

outlet dimensions, and critical arching and ratholing dimensions based on the cohesive strength of the solid.

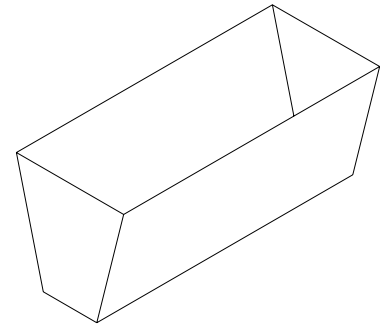
Flowability tests were run on various coals mined in the United States to determine the required hopper angle necessary to obtain mass flow. Mass flow is defined as all of the material in the bin in motion whenever any of the material is

withdrawn. For flow along the walls to occur, the hopper walls must be smooth and sufficiently steep. Tables 1 & 2 show the results of these tests.

**NOTE:** In almost every case, TIVAR® 88 allows mass flow to occur at a shallower wall angle compared to stainless steel.

**Wall Angle for Plane Hoppers**

Coal Sample Identification	Wall Material				Hours at rest
	Time at rest = 0 storage hours		After storage time at rest (hours at right)		
	TIVAR® 88	304-2B SS	TIVAR® 88	304-2B SS	
Lignite	58	81	66	82	72
Western (sub-bitum.)	50	63	55	65	72
Kentucky, -1/4"	49	69	52	69	20
Lignite, pulverized	53	55	***	***	
Lignite, raw	46	67	48	70	72
"Waste" coal	51	55	54	57	24
Minus 1/4"	52	60	61	61	67
Eastern (bitum.)	54	57	54	75	1
Coal, 8% moisture	52	62	52	62	66
Coal, 17% moisture	58	64	62	64	66
Midwestern	51	58	52	72	26
Midwestern	56	61	58	82	26
95% coal, 5% coke (sub-bitum./PRB)	52	70	65	70	65



Plane flow hopper design

**Table 2:** These values represent the hopper angle (degrees from the horizontal) required to achieve mass flow in a plane flow hopper (wedge or transition) with a 1ft. (305mm) x at least 3ft. (914mm) outlet dimension.

\*\*\*No tests were run.

## ▶ FACTORS THAT AFFECT FLOW

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.

Temperature can 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 from humidity in the air and some will lose moisture as it migrates to the bin walls. Moisture migration to the bin walls can cause adhesion to take place<sup>3</sup>.

One of the reasons for poor flow in a hopper can be attributed to adhesion of the bulk material to the hopper wall because of the moisture content. However, there is much less adhesion to TIVAR® 88 than to stainless steel. TIVAR® is hydrophobic (not readily wet by water) and stainless steel is hydrophilic (has an affinity to water).

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## ► SLIDING FRICTION

In addition, the surface friction of TIVAR® 88 is lower than 304-2B stainless steel. In many examples, the hopper wall angle for TIVAR® 88 can be 3° to 12° from the horizontal (depending on the flow properties of the bulk material) shallower than 304-2B stainless steel for flow to occur along the hopper wall.

As a bulk solid flows along the hopper wall, the wall surface wears, resulting in a change to the angle of sliding friction (Phi Prime). Figures 1 and 2 show the results "before" and "after" wear. The bulk solid used for this test was sub-bituminous coal from the Powder River Basin.

Wall friction is the resistance that occurs when a bin's substrate opposes the relative motion of a bulk

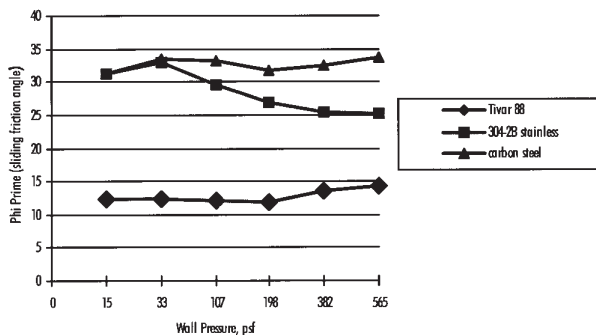
solid sliding along its surface. Wall friction data can be used to anticipate the type of flow that will occur inside a bin and enables calculation of bin loads. Prior to designing or retrofitting a bin, silo or chute, wall friction should be considered.

TIVAR® 88 has an exceptionally low sliding friction angle when compared to stainless steel and carbon steel. The low sliding friction angles associated with TIVAR® 88 can translate into lower construction costs by building more efficiently designed bins with shallower hopper angles.

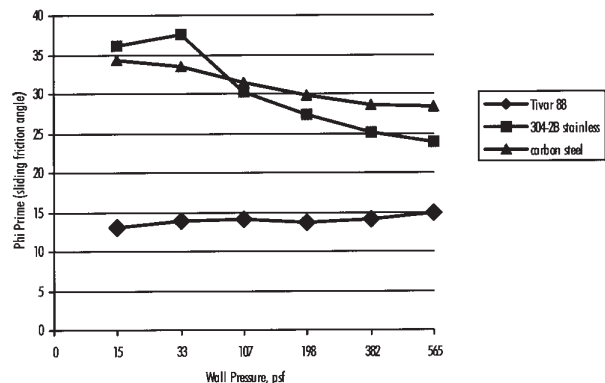
TIVAR® 88 is specified because it promotes mass flow, which eliminates dead regions within a bin and removes a material's tendency to rathole.

In funnel flow bins, material does not flow along the wall until the bin is emptied. This can give the hopper wall time to corrode, encouraging material to adhere to the wall. TIVAR® 88 has excellent corrosion resistance and non-stick characteristics that provide better clean-out.

In the past, TIVAR® 88 has proven, through field experience, to be a cost-effective wall surface lining that provides consistent flow of solids. Due to its low wall friction and superior sliding abrasion resistance, prominent engineering firms have specified TIVAR® 88 as the primary sliding wear surface in new and existing bulk solids handling systems.



**Figure 1:** The angle of sliding friction "before" wear changes as a function of the wall pressure that is expected to occur within the hopper.



**Figure 2:** The angle of sliding friction "after" wear as a function of the wall pressure that is expected to occur within the hopper.

## ► REFERENCES

- [1] Raghu, K., Viverito, J. Carato, P. and Ogle, J.: "Economizing Building Space Using a Single Fuel Silo with Multiple Discharges"; Proceedings of the American Power Conference, Vol. 56 II, 1994, pp. 1550-1555.
- [2] Jenike, A.W.: "Storage and Flow of Solids"; University of Utah, Eng. Exp. Station, Bull. No. 123, Nov. 1964.
- [3] Carson, J.W. and Marinelli, J.: "Solve Solids Flow Problems in Bins, Hoppers, and Feeders," Chemical Engineering Progress, May 1992, pp. 22-28.

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