HOW TO ACHIEVE RELIABLE COAL FLOW AND MAINTAIN PLANT AVAILABILITY

American Electric Power (AEP) Rockport Plant (*photo courtesy of AEP*)

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Foreword

Poly Hi Solidur and American Electric Power (AEP) began their 18-year history with a lining project at the AEP/Rockport facility. Jenike & Johanson, Inc., first assisted AEP with investigating improved coal flow in 1965 at the Muskingum River Plant. AEP is a multinational energy company with a balanced portfolio of energy assets. AEP, the United States' largest electricity generator, owns and operates more than 42,000 megawatts (fossil, nuclear, gas, wind and hydro) of generating capacity in the U.S. and select international markets. Out of this generating capacity, AEP has 22 coal-fired power plants in the U.S., which generate 25,000 megawatts with annual coal consumption of 75 million tons. This makes AEP the largest consumer of coal in the country. AEP is a leading wholesale energy marketer, ranking among North America's top providers of wholesale power and natural gas with a growing wholesale presence in European markets. In addition to electricity generation, AEP owns and operates natural gas pipeline systems, natural gas storage, coal mines and the fourth-largest inland barge company in the United States. AEP is also one of the largest electric utilities in the U.S., with almost 5 million customers linked to AEP's wires in 11 states. The company is based in Columbus, Ohio. AEP Pro Serv is a wholly owned subsidiary of American Electric Power, providing professional technical and maintenance services to the utility subsidiaries of AEP, industrial clients, other utilities, independent power producers, municipalities and cooperatives throughout the U.S.

Poly Hi Solidur, Inc., (PHS), headquartered in Fort Wayne, Ind., with manufacturing, fabricating and sales facilities worldwide, is the world's largest manufacturer of sheet, rod, tube and custom components from specifically formulated grades of polyethylene sold under the TIVAR® brand name. For the bulk material handling market, Poly Hi Solidur offers companies and industries TIVAR® 88 products that exhibit a low coefficient of friction, and high abrasion, corrosion, and impact resistance – and more than 30 years of experience in solving a wide variety of material flow problems using a solutions-oriented approach.

Jenike & Johanson, Inc. (J&J), with offices in Westford, Mass., and San Luis Obispo, Calif., is world-renowned as the leading expert in the flow of bulk solids, helping companies improve the efficiency, reliability, and safety of their operations by reducing or eliminating storage or processing problems. This involves finding economical, practical and often innovative solutions. Jenike & Johanson is recognized worldwide for its expertise in determining a material's handling characteristics by evaluating flow properties using the Jenike Shear Tester covered under the ASTM designation D 6128-00. Much of their engineering research focuses on providing the tools for solving real world bulk solids handling problems, bridging any gaps between science and practice.

Introduction

As the power industry becomes more competitive – due in part to deregulation – and continues implementation of processes to comply with the Clean Air Act, improving operating efficiency at the plant level is critical to growing the bottom line. "Plant availability" or “commercial availability” mean “the ability of a power plant to produce power on an ongoing basis in response to consumer demand.” Because power cannot be stored – it must be produced hour by hour – coal (for coal-fired power plants) must consistently flow hour by hour to meet production needs. A wide variety of coals – bituminous coal, sub-bituminous coal, lignite, synfuels, petroleum coke, waste coals, etc. – and their blends are considered as power plants try to find ways that will enable the units to operate efficiently at the lowest bus bar production cost while still complying with all environmental requirements. Since coal is the single biggest cost to generation, various factors are used to decide what kind and/or blend of coals to burn in a particular unit. Other considerations in the coal selection process – in addition to environmental concerns – include, coal quality/unit performance, availability, price volatility, market conditions, flexibility, cost to upgrade the system to adopt coals of varying characteristics and optimization of plant assets associated with coal procurement. For coal handling operations in particular, various handling techniques need to be implemented to accept a wide range of coals since the design basis was very specific to limited types of coal when the plant was originally built. This involves implementation of design upgrades and innovative operating procedures. The current reality, however, is that one of the most common problems many power plants encounter while switching to different types/blends of coals is flowability.

The focus of this paper is to address power plant personnel with regard to identifying, understanding and correcting flow problems at their facility. AEP and PHS would like to share a few applications and solutions that have been employed over the last 18 years to upgrade AEP’s coal handling system to improve its performance and optimize plant availability. By sharing the experience that AEP and PHS gained through these lining projects, we would like to eliminate the need for companies who experience the same kinds of flow problems to start from ground zero.

Designing a solid fuel handling system based on the measured properties of the fuel to be handled can avoid many of the problems encountered. Knowing these properties is equally as important when considering a retrofit, like a liner – a proven technology that has been around for 30 years – for existing equipment. The following section discusses the most common problems encountered when storing coal, the results of those problems and the approach to solving (and preventing) those problems by changing the way the coal flows.

Bunkers, Silos and Bins – Common Problems

Two of the most common flow problems experienced in an improperly designed bunker, silo or bin (hereafter collectively referred to as silo)[1] are *no-flow* and *erratic flow*.

No-flow (Fig. 1) from a silo can be due to either arching (bridging) or ratholing. Arching occurs when an obstruction in the shape of an arch or a bridge forms above the outlet of a hopper and prevents any further discharge. It can be an interlocking arch, where the particles

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[1]Terms bunker, silo, bin, etc., refer to equipment used to store coal at various stages of handling. For the purpose of analyzing flow through them, they can be considered to be one and the same. By definition, each of these storage vessels consists of a section with a constant cross-sectional area, called the cylinder, and a section where the cross-sectional area changes (typically reducing in size), called the hopper.

mechanically lock to form the obstruction, or a cohesive arch. An interlocking arch occurs when the particles are large compared to the outlet size of the hopper. A cohesive arch occurs when particles pack together to form an obstruction (Fig. 2).

Ratholing (Fig. 1) can occur in a silo when flow takes place in a channel located above the outlet. If the coal being handled has sufficient cohesive strength, the stagnant material outside of this channel will not flow into it. Once the flow channel has emptied, all flow from the silo stops.

<u>*Erratic flow*</u> is often the result of an obstruction alternating between an arch and a rathole. 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 coal 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.

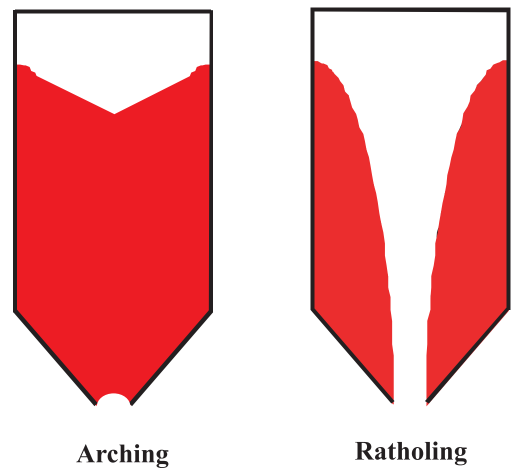

Figure 1. No flow

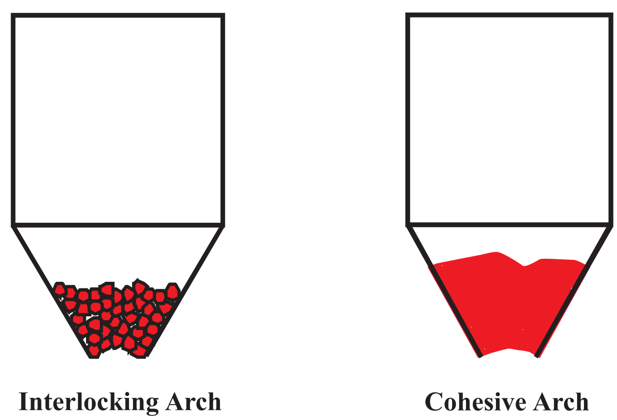

Figure 2. Arching

<u>Results of Flow Problems</u>

Delayed startup time caused by problems related to fuel handling can add significantly to the cost of a plant. While flow stoppages alone can be very costly problems, any stagnant region in a silo can be dangerous, especially when handling coals that are prone to spontaneous combustion. If flow takes place through a channel within the silo, the material outside of this channel may remain stagnant for a very long time (depending on how often the silo is completely emptied), increasing the likelihood of fires.

Collapsing ratholes and arches can cause silos to shake or vibrate.[1] 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.[2, 3]

<u>Flow Patterns</u>

The problems previously discussed occur in silos where flow takes place through a channel formed within stagnant material. This describes a *funnel flow* pattern, in which some material moves while the rest remains stationary during discharge from the silo (Fig. 3). Funnel flow (first-in, last-out) occurs when the sloping hopper walls of a silo are not steep enough and sufficiently low in friction for material to flow along them. Under these conditions, particles slide on themselves rather than the hopper walls, and an internal flow channel develops.

Funnel flow is appropriate only when all of the following conditions are met:

- the material being handled consists entirely of coarse particles – usually 1/4 in. or larger;
- the material is free flowing – i.e., particles do not stick to each other;
- the particles are non-degrading – e.g., spontaneous combustion does not occur when particles are stagnant for an extended duration;
- particle segregation is not a concern.

Most coals today fail some, if not all, of the above criteria. They tend to have a large amount of fines. For example, the composition of many waste coals is up to 50% ash, and since a large portion of this ash is clay, waste coals tend to be very cohesive. This problem is further compounded by high moisture contents associated with outdoor storage in piles and ponds. Lignite, sub-bituminous and certain bituminous coals, too, have a high concentration of fines and tend to be very cohesive. Spontaneous combustion is always a concern with coal. However, many sub-bituminous (e.g., PRB) coals, are of particular concern because of their tendency to heat rapidly and the propensity for explosion due to dusting. For these reasons, flow-related problems are very common in funnel flow silos; therefore, mass flow silos should be used whenever possible.

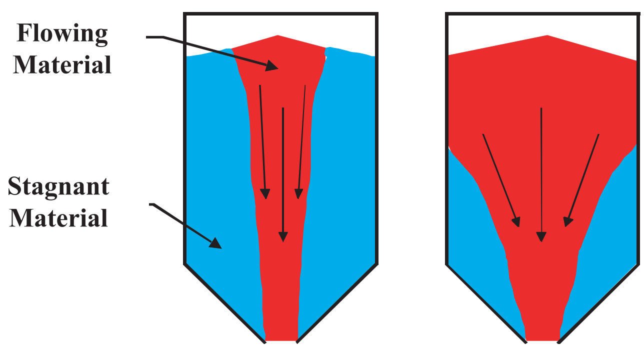

Figure 3. Funnel flow

Mass flow is defined as the flow pattern in which all the material in the silo is in motion whenever any is withdrawn (Fig. 4). Mass flow (first-in, first-out) occurs when particles slide along sloping hopper walls during discharge. Mass flow eliminates ratholing, stagnant material and the associated problem of spontaneous combustion, and maximizes the usable (live) capacity of the silo.

Achieving Mass Flow

In order to achieve mass flow, two conditions must be met: the sloping hopper walls must be steep enough and low enough in friction for the particles to slide along them; and the hopper outlet must be large enough to prevent arching.

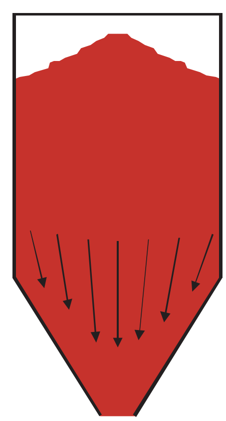

Figure 4. Mass flow

Hopper Angle and Smoothness

How steep and how smooth must a hopper surface be? This answer depends on the friction that develops between the particles and the hopper surface. This friction can be measured in a laboratory using an ASTM test method.[4] A small sample of coal is placed in a test cell and slid along wall surfaces of interest (e.g. stainless steel with #2B, #1 or mill finish, and TIVAR® 88). As various forces are applied normal (perpendicular) to the cell cover, the shear force is measured (Fig. 5). These measurements are used to calculate the wall friction angle, ϕ', which also can be expressed as a coefficient of friction, μ.

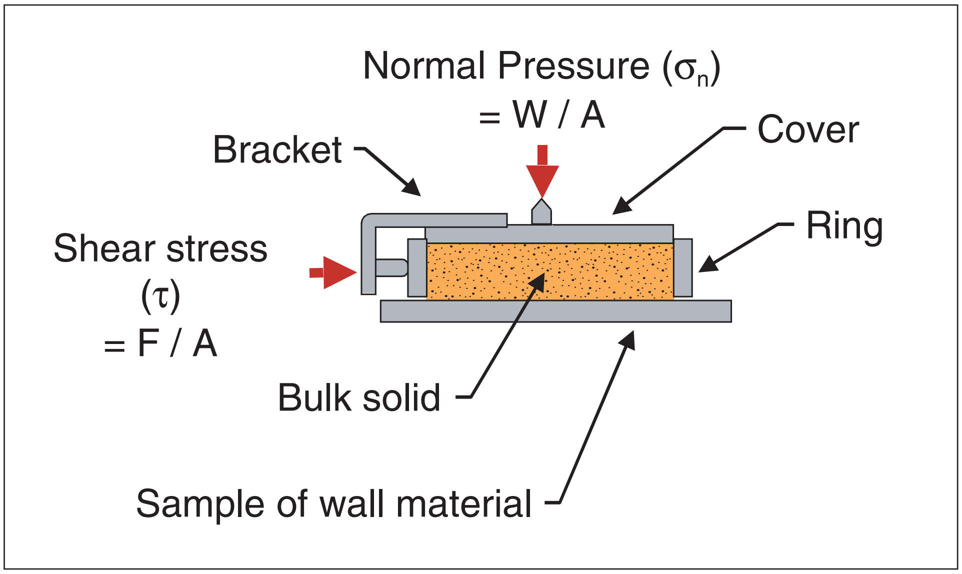

Figure 5. Wall friction test

From the wall friction angles, limiting hopper angles for mass flow can be determined using a method developed by Dr. Andrew Jenike.[5] These angles are used as design criteria for achieving mass flow in new hopper and bunker installations, and are invaluable when considering retrofit options for liners, coatings and polished surfaces with existing designs.[6]

In general, a number of factors can affect wall friction for a given coal, such as:

- *Wall Material*. Generally, smoother wall surfaces result in lower wall friction (there are exceptions), thus, shallower hopper angles are sufficient for mass flow to take place.
- *Bulk Solid Condition.* Moisture content, variations in material composition and particle size can affect wall friction.
- *Time at Rest.* Some coals adhere to a wall surface if left at rest in a hopper. Wall friction tests can be performed to measure the increase in wall friction (if any) due to storage at rest. If adhesion takes place, steeper hopper angles or a lower friction wall material are required to overcome it.
- *Corrosion.* Wall materials that corrode with time generally 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 can be performed to determine the effect on wall friction, as well as calculate the amount of wear expected. A patented wear tester developed by Jenike & Johanson, Inc., can be used to estimate the amount of abrasive wear in a particular silo due to solids flow.[7] These tests allow for a prediction of the useful life of a liner or surface based on its thickness, which can be an important economic consideration.

Hopper Outlet Size

The second requirement for mass flow is that the outlet must be large enough to prevent arching. As discussed previously, two types of arches are possible. Interlocking arches can be overcome by ensuring that the outlet diameter is at least six to eight times the largest particle size in a circular opening, or the width is at least three to four times the largest particle size in a slotted opening. (Slotted outlets must be at least three times as long as they are wide for such conditions to apply.)

The second type of arch, namely a cohesive arch, can be analyzed by determining the cohesive strength of the material. First, the flow function of the coal (i.e., its cohesive strength as a function of consolidating pressure) is measured through laboratory testing. Tests are conducted using an ASTM described direct shear tester.[4] In this test, consolidating forces are applied to material in a test cell, similar to the wall friction test, and the force required to shear the material is measured. (Fig. 6) The measured property directly relates to a coal's ability to form a cohesive arch or a rathole. Once the flow function is determined, minimum outlet sizes to prevent arching or ratholing (in funnel flow) can be calculated through a series of design charts also published by Jenike.[5]

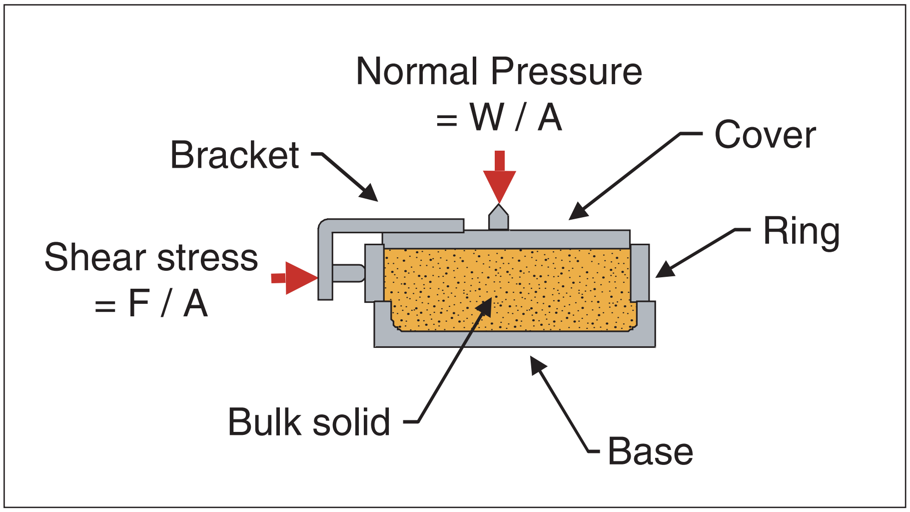

Figure 6. Shear test

A number of factors affect the minimum outlet sizes required, including:

- *Particle Size.* Generally, as particle size decreases, cohesive strength increases, requiring larger outlets to prevent arching.
- *Moisture.* 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, many bulk solids (including coal) tend to become slurry-like and their cohesive strength decreases.
- *Time at Rest.* Similar to wall friction, some coals exhibit an increase in their cohesive strength if left at rest for some period of time. Cohesive strength can be measured using a direct shear tester simulating storage time at rest.

Many of the coals, like sub-bituminous PRB, are high in fines and moisture, which when stored at rest, adversely affects the arching potential. Also, most of the waste fuels being used today in industry, such as bituminous gob and anthracite culm, are inherently bad actors because they are high in everything: high fines/high ash (much of which is clay), high moisture (due to open stockpiles and ponds), and storage time at rest. A robust design requires testing samples from multiple sources over a range of moisture contents.

Other Silo Outlet Considerations

Feeder Design

In addition to ensuring that reliable flow takes place in the hopper previously described, it is necessary for the entire cross-sectional area of the outlet to be active. A restricted outlet, such as a partially open slide gate, will result in funnel flow with a small active flow channel regardless of the hopper design. It is, therefore, imperative that a feeder be capable of continuously withdrawing material from the entire outlet of the hopper.[8] This feature allows mass flow to take place in the hopper above, if it is so designed. It also reduces the potential for ratholing in funnel flow by keeping the active flow channel as large as possible.

Standpipe Design

There are two purposes for a standpipe: to minimize the amount of gas leakage into the silo from a pressurized boiler, and to minimize the upward (positive) gas pressure gradient that can actually increase the arching potential of the coal. The finer the coal, the more adverse this latter effect will be. Proper analysis and design are required to determine the size and height requirements for the standpipe.

Typical Solutions

The key to reliable handling of coal is to design the handling system equipment based on the measured flow properties of the type of coal to be handled. Given the variability of coals, it is imperative to test samples from multiple sources over the expected range of moisture contents. However, if the plant is already built, there are three methods available to address the types of problems mentioned here – change the material, change the operating procedures or change the equipment. The methods described here also apply to new plant design.

Change the Material

The material can be changed by any of the following methods. Coal moisture levels can be lowered by using covered storage, by mechanical drying, or by blending wet and dry materials. Increasing the particle size by screening lowers the cohesive strength (arching/ratholing tendency). Blending coal from different sources can change the composition of the coal.

Change the Operating Procedures

Often, changing fuel handling operational procedures is extremely effective in reducing handling problems, and in many cases, it is the most economical solution. If the coal gains cohesive strength after being stored at rest for extended periods, limiting the time of storage at rest can reduce its arching tendency. If the combination of the silo design and the coal flow properties result in stagnant material, reducing the amount of material being stored (limit silo capacity and thus head) can reduce the amount of material remaining stagnant. Frequently drawing the material down to a low level, or emptying the silo on a regular basis can help with clean-off and reduce the amount of stagnant material.

Flow aids can be very effective in breaking down arches, but only after an arch has formed (due to material impact upon filling or after storage at rest) and they should be turned off once flow has resumed; however, if material flow has not resumed and the flow aids are used repeatedly, the coal will become more compacted, and trying to restart flow with these devices will be futile.

If the coal silo has dual outlets, both outlets must be used simultaneously. Use of only one outlet will probably result in severe eccentric silo wall loading and compacted, stagnant material over the non-flowing outlet.

Change the Equipment

Consideration should be given to changing the equipment only after confirming the handling properties of the coals to be handled, thus eliminating the guesswork. After all, a significant capital investment was laid out for this equipment in the first place. But changes to the equipment may be the most effective and long-term economic solution. Based on the measured flow properties of the coals being handled, the modifications required can range from lining the existing hopper with a less frictional liner, like TIVAR® 88 (Fig. 7), to enlarging the outlet and steepening the angle of the lower hopper section. Changes to the feeder, standpipe and/or the feeder interface may also be required.

Figure 7. Typical hopper liner installation in progress

CASE STUDIES

The following case studies represent some of the coal-related challenges faced at several AEP facilities – and how those challenges were eliminated using the results obtained from the Jenike Shear Tester, power plant engineering experience, good housekeeping practices and TIVAR® 88 liners.

Plant Name: Rockport Units 1 & 2
Application: 600-800 Ton Silos (28 Conical Sections)
Bulk Material: PRB and Bituminous Coal Blend
Substrate: Stainless Steel
Problem: Arching/Bridging, Ratholing, Fires

In 1984, the AEP Rockport plant (2 – 1,300 MW units) began burning PRB (Powder River Basin) sub-bituminous coal. Unlike bituminous coal, PRB coal (mined in Wyoming and southern Montana) exhibits higher percentage fines and moisture. Ratholing and bridging problems were noted in the storage silos of Unit 1 (14 silos) during initial startup even though the 65° and 68° conical hopper sections were completely lined with 16-gauge type 304 stainless steel sheet with a 2B finish. Sledgehammers, air lances, vibrators and portable heaters were used in vain to try to restore the coal flow. The interrupted coal flow due to wet coal caused load curtailment. J&J was contracted to evaluate the flow and recommend a course of action to change the flow pattern from funnel flow to mass flow in the silos. They first tested the PRB coal to be handled at the anticipated moisture content and storage conditions (continuous flow as well as three days storage time at rest) to determine the handling properties. Based on their tests on various wall liners, J&J concluded that the surface of the 304 stainless steel sheet with a 2B finish was not smooth enough to obtain mass flow and recommended the installation of TIVAR® 88 liners in conjunction with an air blaster system.

Results: Following the installation of the TIVAR® 88 liner and air blaster system, plugging problems were greatly reduced. By reducing plugging – which means less coal stagnation – the potential for spontaneous combustion was also reduced. After the plant experienced the success of Unit 1, similar modifications were made to the Unit 2 silos.[9, 10]

COMMUNICATION

Although each AEP plant's operation is unique, achieving mass flow from each plant's storage silos/bunkers/hoppers is the ultimate goal to optimize coal-handling performance. Communication among the various plants has been crucial in the company's efforts to achieve that goal in the most effective way possible. Sharing information regarding successes and failures among plant staff has resulted in quicker, more effective long-term solutions to individual plant flow problems, as evidenced by the following case study.

Plant Name: Tanners Creek Unit 4
Application: 2,350-Ton Bunker (11 Outlets)
Bulk Material: Bituminous & PRB Coal Blend
Substrate: Stainless Steel
Problem: Arching/Bridging, Ratholing

AEP's Tanners Creek plant Unit 4 (500 MWs) experienced arching, bridging and ratholing problems in all 11 outlets when the plant started blending the bituminous coal with PRB coal, even though each of the 11 pyramidal hoppers had wall angles of 63° and 64°, while the valley angles were approximately 55° from horizontal. The plugging problems became more severe whenever it rained or when the moisture content of the coal was higher than normal. When plugging occurred, air lances and sledgehammers were used to try to dislodge the blockages. These methods were very labor intensive and did not eliminate downtime, or prevent new instances from recurring. During an AEP group seminar in 2000, plant personnel learned about another AEP plant that had experienced many of the same problems. Staff from that plant shared their successful use of TIVAR® 88 liners to reduce or eliminate plugging problems, prompting Tanners Creek to line the Unit 4 bunker with TIVAR® 88.

Results: Tanners Creek realized immediate improvements in coal flow after the installation of the 1/2"-thick TIVAR® 88 liner. Man-hours devoted to unplugging the hoppers have been dramatically reduced and the unit receives coal almost uninterrupted.

<u>Spontaneous Combustion</u>

Most bunker fires are caused by spontaneous combustion and it is a generally accepted fact that stagnant coal (coal that remains stationary in a bunker or bin for an extended time) – usually caused from a funnel flow pattern – is one of the main causes for spontaneous combustion. The longer coal is allowed to remain stagnant, the more susceptible it becomes to self-ignition.[11] Therefore, the ideal situation is to keep only fresh coal in the bunker – an environment that can be achieved with a mass flow pattern (first-in, first-out). In fact, according to NFPA 850 Section 5-4 and 8503 Section 2-6, mass flow is necessary in order to prevent stagnant coal build-up, which is one of the main elements leading to bunker fires.

Converting a silo to mass flow requires determining the effectiveness of potential liner materials for the existing silo geometry before installing the liner. This can only be accomplished by using the test methods described previously. Lining coal bunkers with TIVAR® 88 is one proven method for achieving mass flow and eliminating the potential for stagnant coal and related bunker fires. [12]

Coal will not readily hang-up or cement itself to TIVAR® 88 under normal conditions. The low friction surface of TIVAR® 88 promotes the flow of coal along the bunker walls, which is associated with a mass flow discharge pattern. This flow pattern would eliminate regions of stagnant coal that could lead to spontaneous combustion, as illustrated in the following case study.

Plant Name: Kammer Units 1, 2 & 3
Application: 3 Bunkers @ 960 Tons (5 Outlets/Bunker)
Station #3 Reclaim Hoppers (4 Outlets)
Bulk Material: Bituminous Coal
Substrate: Stainless Steel and Concrete
Problem: No Flow, Hot Coal/Fire

Kammer Units 1 through 3 (210 MWs each) experienced coal flow problems in both the bunkers that were lined with 304-2B stainless steel and in the concrete reclaim hoppers (Figs. 8, 8a) that were partially lined with stainless steel in the lower portion of each hopper near the outlet. In some years, the plant had load curtailments due to serious flow problems from wet coal. Contributing to the coal flow problems were the patches placed on worn sections of the stainless steel in several places. There were also safety concerns. A couple of small fires, due to self-ignition of stagnant coal, resulted in damage to several coal feeder belts. Fortunately, no personnel were injured.

Figure 8. Kammer reclaim hopper - before TIVAR® 88 installation

Figure 8a. Kammer reclaim hopper - during TIVAR® 88 installation

Plant personnel were challenged to improve coal flow in a long-term, economical way. Bunker trims (the process of running a coal bunker empty and knocking stagnant coal loose with air lances or other mechanical means) had been conducted quarterly with poor results; coal would begin sticking almost immediately after each "trim". Plant personnel experienced back injuries during the cleaning process.

Based on experience at other AEP plants, Kammer decided to install 1/2"-thick TIVAR® 88 liners over existing 304-2B stainless steel hopper walls. The initial installation took place during a planned outage in mid-1996.

Results: Stagnant coal problems in the bunkers and bunker trims have been eliminated. According to plant staff, only routine maintenance has been needed thus far, and there have been little, if any, coal flow problems in the bunkers since the liners were installed.

Installation Techniques

Using the proper technique to install TIVAR® 88 for a specific application is as important as the material itself in determining the final success level of the liner. It is highly recommended that either an experienced installation contractor performs this task or that the individual performing the installation receive specific instructions or site supervision from PHS prior to the installation. Utilizing over-sized panels with extrusion welds reduces the number of seams and fasteners (Figs. 9, 10), further minimizing potential ledges or protrusions on the surface that could cause a disruption in flow. Precision surface scoring is used to form the material to tight corners or bends (Fig. 11), which results in a perfect fit. Finally, stainless steel leading edge protectors (Fig. 12) are installed over the top

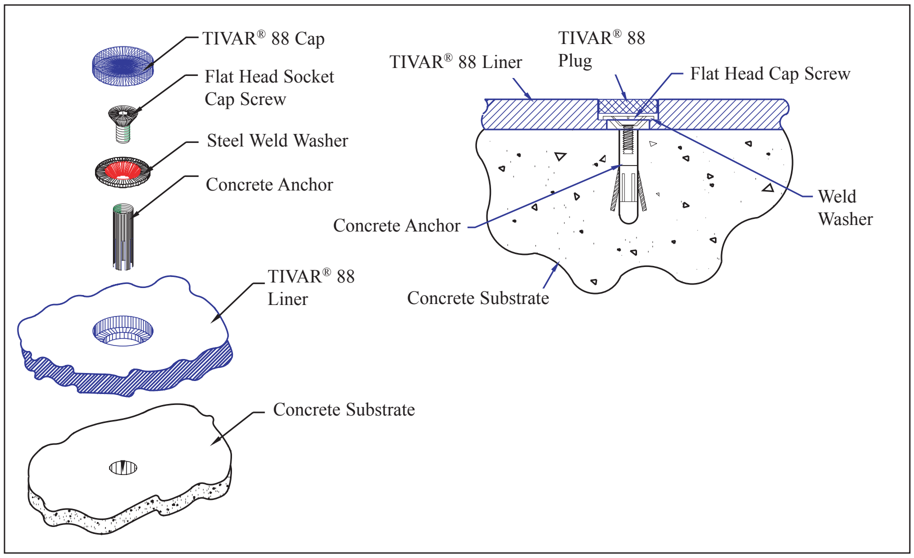

Figure 9. Weld washer assembly attached with a concrete anchor using a TIVAR® 88 liner and plug.

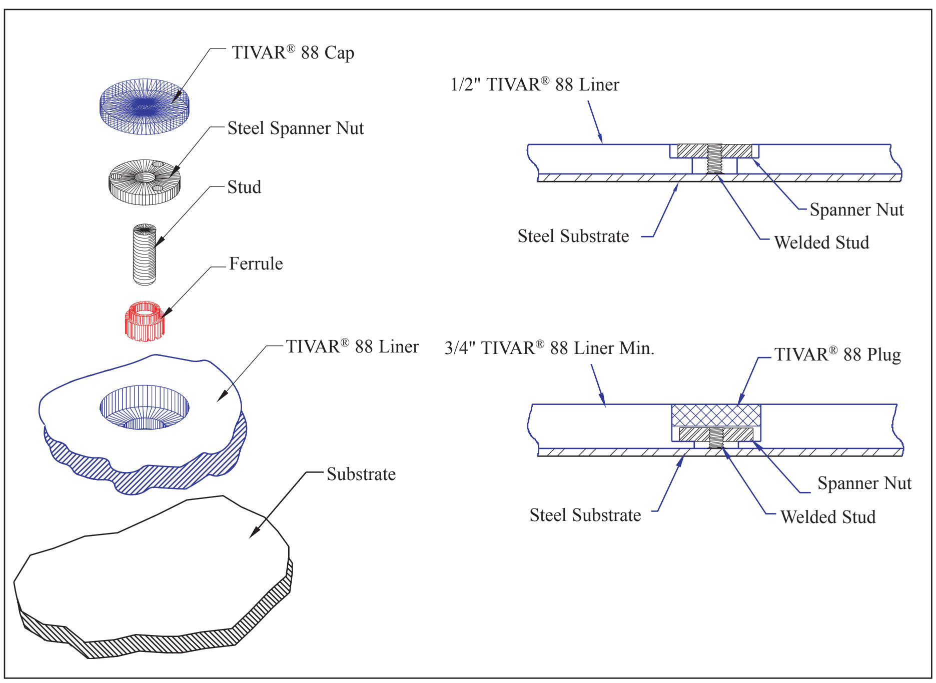

Figure 10. Stud and spanner nut assembly

edge of the liner to ensure that the material remains flat, thereby preventing bulk materials from migrating behind the liner and pulling it away from the substrate.

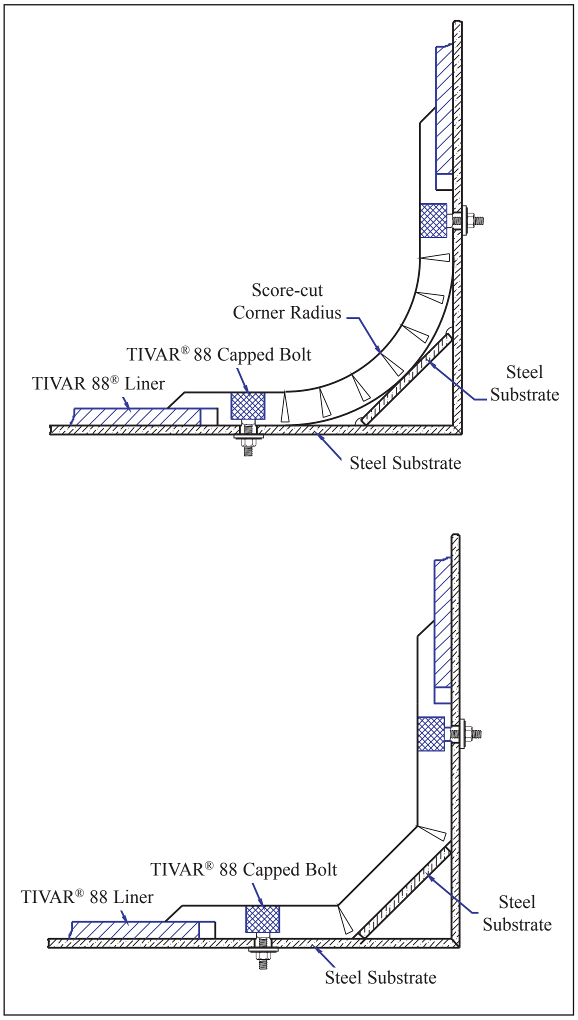

Figure 11. Installation options for valley angles and corners

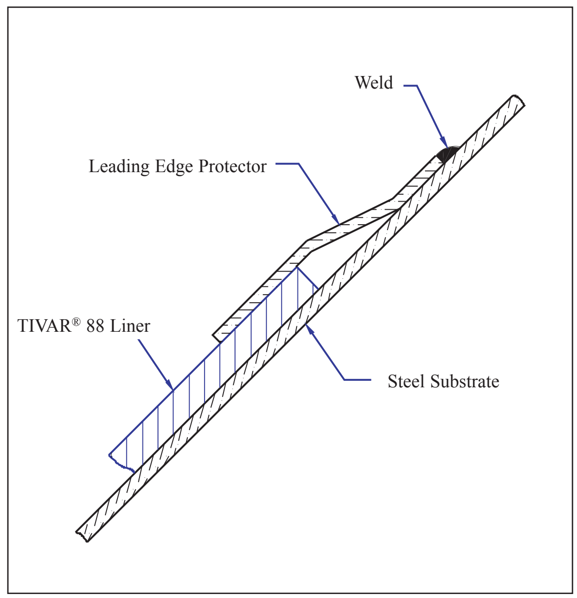

Figure 12. Leading edge protector

Plant Name: Muskingum River Units 1, 2, 3 & 4
Application: 4 Bunkers @ 2,350 Tons
Bulk Material: Bituminous Coal
Substrate: Gunite and Stainless Steel
Problem: Sticking, Bridging

In 1997, Muskingum started a fuel switch test in Units 1 through 4 with a Pittsburgh #8 coal, which has a lower sulfur content (mid-range) and produces higher BTUs than the coal they were currently burning.

Units 1 and 2 (205 MWs each) are identical in size and shape. Each unit has a coal bunker with 8 pyramidal-shaped discharge hoppers with sloping walls of approximately 63º and valley angles at 54° from horizontal (Fig. 13). The hopper walls were lined with gunite. The gunite

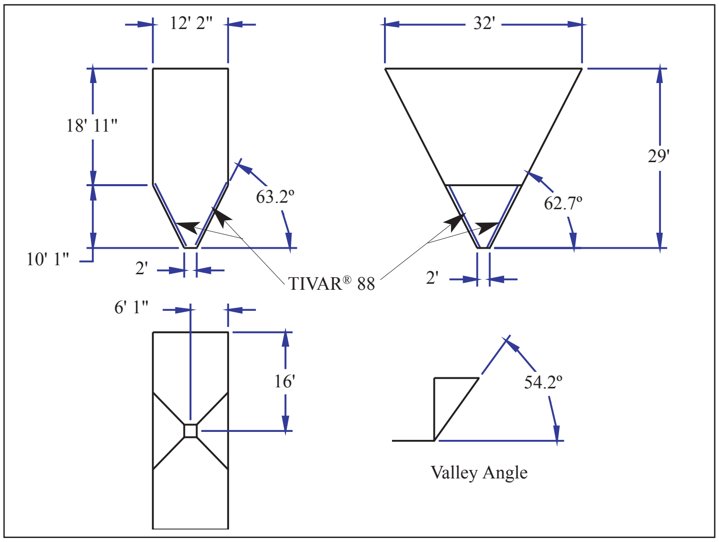

Figure 13. Representation of Muskingum's hoppers

constantly cracked and chipped as a result of long-term use, and had to be repaired on a regular basis during general boiler inspect/repair outages.

Units 3 and 4 (215 MWs each) are also identical in size and shape. Each unit has a coal bunker (Fig. 14) with 5 pyramidal-shaped discharge hoppers with 63° and 65° sloping walls and valley angles at 53° from horizontal. The hopper walls in these units are lined with 304-2B stainless steel.

During the test burns, several problems were encountered in Units 1 and 2 due to the wet coal sticking to the hopper walls as well as plugging and bridging over the outlets. A significant number of man-hours were spent during the one-week test burn to unplug the hoppers to allow the coal to flow freely. Units 3 and 4 had fewer problems with coal flow due to the lower surface friction of the 304-2B stainless steel surface compared to the gunite in Units 1 and 2. Although the stainless steel surface was smoother than the gunite, there were small tears and imperfections in the stainless steel liner due to impact and wear. With fewer flow problems in Units 3 and 4, these two units became a secondary priority and attention was focused on Units 1 and 2. Plant management decided to install 1/2"-thick TIVAR® 88 liners over the top of the gunite in Units 1 and 2 in 1999/2000 to promote flow along the hopper walls and eliminate plugging.

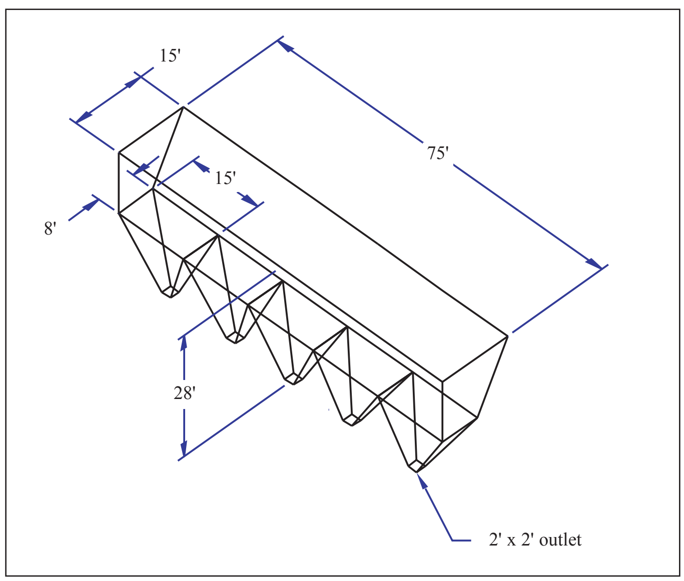

Figure 14. Typical coal bunker

Results: Coal flow was drastically improved and plugging problems were virtually eliminated. However, while focusing on the bridging/no flow problems in Units 1 and 2, an unexpected fire broke out in Unit 3. The fire was attributed to the stagnant coal that was sticking to the tears and imperfections in the stainless steel liner. The fire was a wake-up call for everyone involved.

With the successful performance in Units 1 and 2, the decision was made in 2001 to install TIVAR® 88 in Units 3 and 4. Since then, coal stagnation has been eliminated and the coal flows consistently and reliably. Satisfied that all flow problems were addressed, the plant successfully switched over to Pittsburgh #8 coal in 2002.

As an additional benefit, both maintenance costs and safety issues were reduced. Prior to the TIVAR® 88 lining, the bunkers feeding the coal with a particle size of 95% minus 4 mesh in the cyclone fired units, required cleaning approximately every 4-6 weeks. This required 2-3 workers for nearly 12 hours performing a dangerous task. Safety issues are always a concern when you must manhandle an 80-foot-long one-inch diameter hose with a 10-foot-long air lance attached to it to dislodge the sticking coal in each hopper. Not only was this cleaning action dirty, but it also forced the operator into an awkward position. After the TIVAR® 88 liner was installed, the necessity of this cleaning practice was eliminated. The operator is now able to watch the coal discharge completely from the bunker at which time they begin to refill it.

Impact of Coal Type on Flowability

Different coals have different characteristics. Measuring the effect of these characteristics on the flow properties is essential in determining a particular kind of coal's flowability. In addition to coal characteristics (contents of clay, moisture and fines), valley angles of the various hopper designs also impact flowability. For older plants in the AEP system, the shallow hopper design was one of the primary causes of the flow problems. The Glen Lyn plant, located in Virginia, is an example of this scenario.

Plant Name: Glyn Lyn Units 5 & 6
Application: Rail Unloading Hopper
Bulk Material: Bituminous Coal
Substrate: Stainless Steel
Problem: Sticking, Bridging, Frozen Coal in Winter

Since the inception of the plant, serious flow problems were evident at the car shakeout rail unloading hopper, especially during winter months. Coal hang-ups were occurring on the sides and valley angles of the pyramidal hopper. This was plugging the hopper outlet, causing feed interruptions to the belt feeder underneath the opening and impacting the rail unloading process. It was extremely difficult to manually clean the hopper by rodding/air lancing, due to the fact that the hopper top was occupied by the railcar and the feeder belt was running at the hopper bottom. The frozen coal during the winter aggravated the situation further and also presented a safety concern. In 1997, Poly Hi Solidur designed, manufactured and supervised the installation of a 5/8"-thick TIVAR® 88 lining system for the hopper.

Results: The thicker sheet absorbed the impact of the falling coal from the railcar. The score-cut radius corners reduced sticking in the valley angles. This TIVAR® 88 application has almost eliminated the need for manual cleaning and has improved the unloading operation significantly. It has also eliminated the safety concern issues.

Conclusions

The key to reliable handling of coal is to design the handling system equipment based on the measured flow properties of the materials to be handled. The "try it and see if it works" method should be avoided. Using ASTM test methods[4], hopper angles for mass flow can be determined by measuring wall friction, and the minimum outlet size to prevent cohesive arching can be calculated by measuring the cohesive strength of a material. These are two of the major requirements for designing a mass flow silo.

The potential for arching (and ratholing) is directly attributable to fines content, moisture content and storage time at rest. Many of today's coals, like sub-bituminous PRB, are high in fines and moisture, characteristics which adversely affect the arching potential when these coals are stored at rest. Also, most of the waste pond recovered coals being used today in industry are inherently bad actors because they are high in everything: high fines/high ash (clay), high moisture and storage time at rest. A robust design requires testing samples from multiple sources over a range of moisture contents.

Preventing stagnant regions of coal in a silo is an essential part of preventing spontaneous combustion. This requires either *complete* emptying of the silo on a regular basis, or mass flow to ensure the elimination of stagnant material. In many instances, lining an existing silo's geometry with TIVAR® 88 can reduce the wall friction sufficiently to induce mass flow.

Basically, there are three methods available for alleviating coal-handling problems in an existing plant: change the material (coarser, drier), change the operating procedures (limit storage time, empty silo frequently), or change the equipment (increase outlet size, steepen hopper, and/or install less frictional hopper liner).

In all practicality, coal cannot be changed solely due to handling problems. The selection of coal for a power plant depends on a variety of factors as described in the introduction of this paper. Complete redesigns of existing systems are cost-prohibitive, although certain design retrofits can be cost-justified. However, as illustrated by the case studies presented, AEP dramatically improved coal flowability at its plants by performing design retrofits utilizing the experience, knowledge and proven technologies of a lining expert such as Poly Hi Solidur and a bulk material handling expert such as Jenike & Johanson.

AEP has also focused its attention on improvements in operating procedures to reduce load curtailments. With almost 100 years of experience in power plant engineering, design and construction, AEP has performed major process improvements such as the development of the Coal Pile Management Program [13, 14] that allows the company more flexibility to operate under different conditions and still optimize power plant efficiency.

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