How Northern States Power solved handling problems associated with sub-bituminous coal

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CASE HISTORY

COAL

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Abstract —

This paper reviews storage and handling problems of sub-bituminous coal mined in the Western United States and how Northern States Power (NSP) at its Riverside Generating Station solved them.

The paper discusses the comparative differences in the storage characteristics of sub-bituminous coal versus bituminous coal. This will include a review of common bunker geometries, construction and internal surface finishes and how these affect coal flow.

A portion of the paper addresses the issue of spontaneous combustion with sub-bituminous coal in storage bins, bunkers and silos. An analysis of the problem is presented based on actual experiences of power stations in the United States. Risk and liability of spontaneous combustion will be considered along with its financial impact.

Some theories state that spontaneous combustion is likely to occur in storage bins that contain regions of stagnant coal due to limited flow conditions. These "dead" regions are usually the result of funnel flow bin design. In contrast, mass flow bins, in which all of the material is in motion whenever any of it is withdrawn, eliminate stagnation.

The different types of bunker flow patterns are described along with experiences of handling sub-bituminous coal. We discuss commonly used flow correcting solutions, such as inserts and hopper liners, that minimize or eliminate flow problems within coal storage systems.

At the Riverside plant, the original funnel flow bins were converted to mass flow for the purpose of eliminating the "dead" regions. We describe this conversion process, including the analysis leading to the implementation of the project. We will review the economic justification, operating performance and overall solution.

Many power stations have similar problems handling certain coals and are not aware that it is possible to eliminate these problems to ensure a reliable storage and discharge system. The problem becomes worse as plants switch fuels to comply with the Clean Air Act. Many coal storage bunkers are not designed for handling cohesive, poor-flowing coal, which are characteristics of low-sulfur sub-bituminous coal mined in the Western United States.

Background —

NSP's Riverside plant is a two-unit, 384 MW coal-fired station located in Minneapolis, Minnesota. Its coal bunkers in Units 7 and 8 were built in 1949 and 1963, respectively. They were originally designed to handle relatively free-flowing bituminous coal.

At the time of construction, bunker design was based on storage capacity, space constraints and process requirements. The flow properties of the coal being handled were not a priority. Flow problems were experienced in bunkers handling bituminous coal but were not considered unusual. Companies learned to live with the problems rather than search for methods to alleviate them.

After switching to low-sulfur sub-bituminous coal from the Powder River Basin, the coal storage bunkers at this plant experienced several fires and an explosion resulting from spontaneous combustion.

The most recent incident happened in Unit 7, when an explosion occurred in the coal storage bunker in November 1993. It was determined that the coal in the bunker ignited due to spontaneous combustion at the same time that coal dust from the dust collection system was being conveyed back into the bunker. The dust exploded when it came into contact with the hot coal.

As a result of the Unit 7 bunker explosion, NSP management established a task force to investigate the situation and develop a corrective solution to eliminate fires and explosions at all of its coal-fired plants. This task force is known as "Operation Cease Fire."

A forced outage in Unit 8 at Riverside, beginning on March 6, 1994, was an opportunity for the task force to implement flow correcting modifications, designed to eliminate coal stagnation in the bunker.

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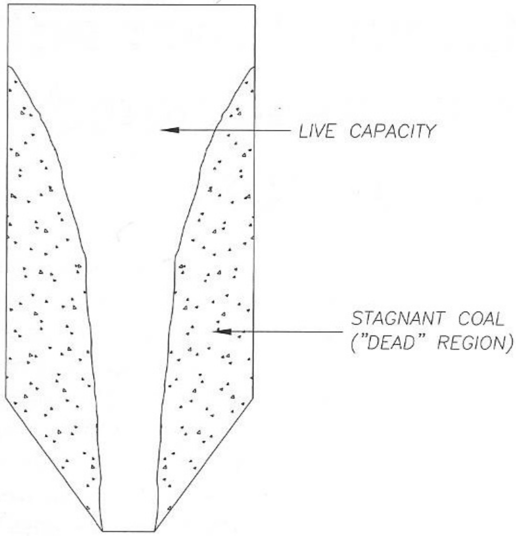
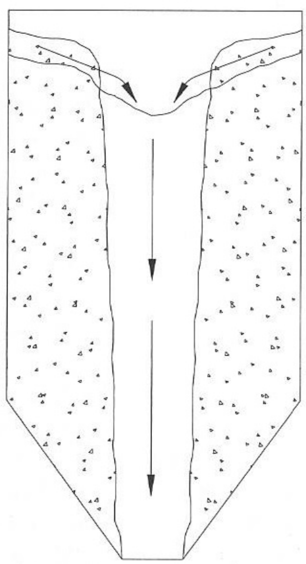


Figure 1— Stagnant coal forms in the bunker and severely reduces the bunker's live capacity.

Figure 2— Material outside the flow channel is stagnant.



Evaluation of the Unit 8 coal bunker —

The coal bunker was found to contain very large regions of stagnant coal due to the flow pattern in the bin. These "dead" regions started to form in the valley angles and would enlarge outwardly along the bunker walls due to the cohesive nature of the sub-bituminous coal and the rough surface of the gunite. Eventually these regions of stagnant coal severely reduced a large portion of the bunker's "live" capacity, as shown in Fig. 1. This coal is soft with a moisture content of up to 37%, that allows it to easily compact or consolidate during storage. The situation is not expected to improve as long as this flow pattern continues in the bunker.

The funnel flow pattern was primarily due to the bunker geometry and condition of the hopper wall surfaces. The hopper walls were not smooth or steep enough to force flow along them. Funnel flow can be described as a first-in last-out sequence, which means that coal introduced first into the bunker may remain there indefinitely.

Funnel flow discharge is characterized by a condition in which the hopper wall angles are too shallow or surfaces too rough for coal to slide along them. As a result, material flows preferentially through a funnel-shaped channel located directly above the outlet, while material outside the flow channel is stagnant [1] as shown in Fig. 2. Ratholes and arches (Fig. 3) form readily when non-free-flowing bulk solids are handled in funnel flow bins.

Funnel flow bins are for coarse free-flowing bulk solids that do not segregate or degrade with time; however, they are not suitable for cohesive bulk solids.

When coal remains stagnant long enough, it becomes highly susceptible to spontaneous combustion. Non-flowing or "dead" regions are a result of funnel flow in most situations. Theoretically, the stagnant coal may never discharge if it solidifies along the bunker walls. Mechanical means may be necessary to break it up and dislodge it.

The task force concluded that coal stagnation caused the fires. They began their search for a solution to eliminate the "dead" regions within the bunker. Their choices were limited to doing nothing, installing more flow promotion devices, changing the hopper wall material to one with a lower surface friction or modifying the existing bunker geometry.

The original coal bunker, as shown in Fig. 4, was equipped with 20 air cannons, 2 on each of the 5 pyramidal shaped hoppers and 10 on the vertical wall section of the bunker. the vertical and sloping wall sections of the bunker were coated with a 2" thick gunite surface down to the top of the five discharge hoppers that were constructed of stainless steel.

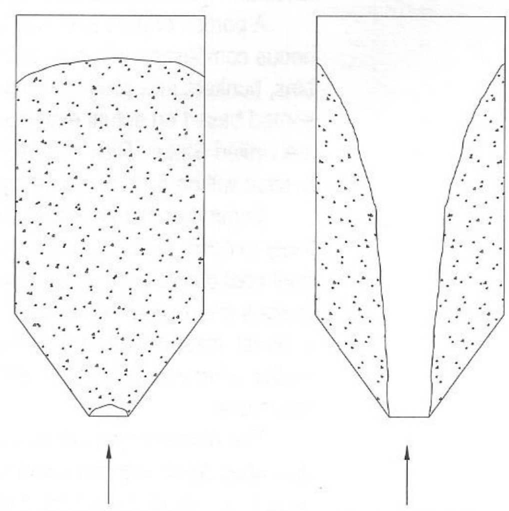


Figure 3— Ratholes and arches form readily when non-free-flowing bulk solids are handled in funnel flow bins.

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Close inspection of the five discharge hoppers revealed that coal flow was limited to a central core immediately above the outlets. This fact was established by excessive discoloration and corrosion on the stainless steel walls. A highly polished area on the stainless steel existed immediately above each discharge outlet indicating that flow was confined to a relatively small central channel. The NSP engineers estimated this flow pattern reduced the "live" storage capacity of the bunker by 20%.

NSP contacted Poly Hi Solidur and inquired about the performance of a TIVAR 88 liner, thinking it may be the complete solution to the flow problems, since they had a previous experience with TIVAR 88 at their Black Dog plant (Burnsville, Minnesota) in a rail dump receiving hopper. Poly Hi Solidur engineers studied the current design of the bunker along with the current coal flow problems and determined that a solution was possible, but knew that it would require further analysis in order to substantiate the effectiveness of a TIVAR 88 liner. Poly Hi Solidur referred NSP to Jenike & Johanson, Inc., consultants located in Westford, Massachusetts, and San Luis Obispo, California, who have expertise in the flow of solids from bins and hoppers.

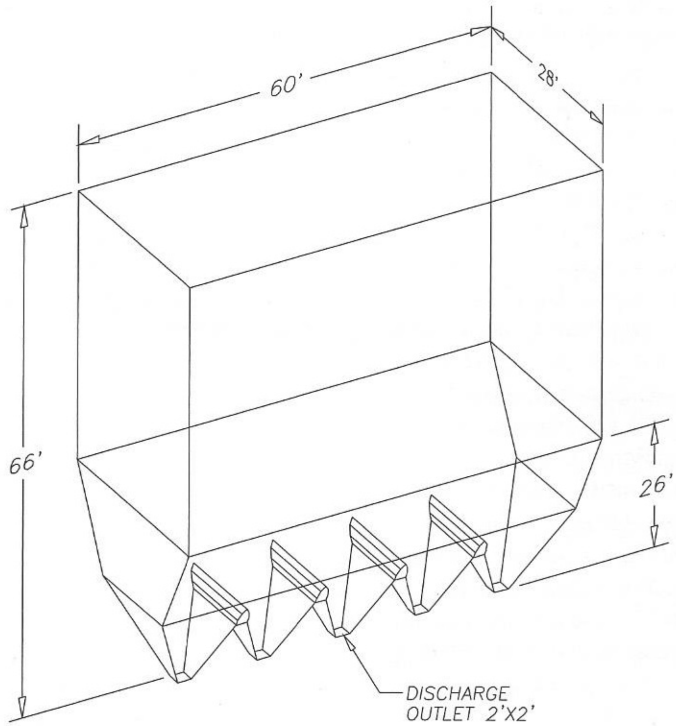

Figure 4— Original design of the bunker in Unit 8. The vertical and sloping walls were coated with 2" thick Gunite and the hoppers were constructed of stainless steel. The 20 air cannons are not shown.

Solution —

In order to prevent the fires, it was necessary to eliminate the regions of stagnant coal. In mass flow design, all of the bulk solid in the bin is in motion whenever any of it is withdrawn. It is a first-in first-out flow pattern, as shown in Fig. 5. This flow pattern eliminates stagnation or "dead" regions of non-free-flowing bulk solids. It provides complete and reliable uninterrupted flow from the bin.

The engineers at NSP knew that bunker modifications were required to change the existing funnel flow design to mass flow design. A change of this nature affects the pressure distribution within the hopper during discharge. They also knew the flow properties of the coal could have a major influence on the proposed modification. Therefore, NSP engineers contacted Jenike & Johanson's California office to test a representative sample of the coal and make recommendations for modifications to the bunkers.

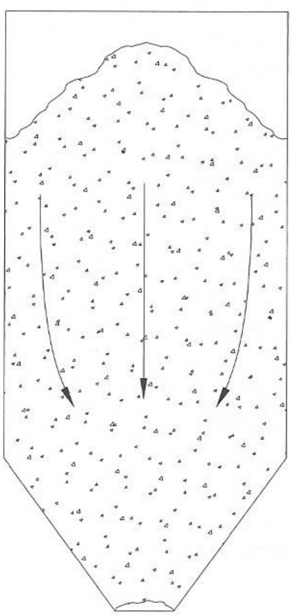

***Figure 5—** Mass flow is one in which **all** of the bulk solid in the bin is in motion whenever any of it is withdrawn.*

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Samples of the coal were collected and flow property testing began using the Jenike Shear Tester [2] (Fig. 6), which measures friction between coal and various wall materials. Coal samples are placed in a retaining ring that sits on top of the proposed wall materials. Weights are applied on the coal to simulate the normal pressure that will occur in the bin. The coal is then forced to slide along the proposed wall material and the shear force is measured. The proposed wall materials chosen for this test were 304 #2B stainless steel, aged (corroded) carbon steel and TIVAR 88. The Jenike & Johanson Flow Properties test Report confirmed that carbon steel would be unsuitable as a wall material in the bunker because the coal adhered to the carbon steel surface. It also showed the shear force on TIVAR 88 was lower than on 304 #2B stainless steel. [3]

The Flow Properties Test Report also indicated that the sub-bituminous coal at 37% moisture content has enough strength to form stable ratholes in a funnel flow hopper even under continuous flow conditions. The flow property tests indicated the critical arching dimension of the coal would increase from 1.5 ft. diameter during continuous flow to 6.2 ft. diameter after three days of storage at rest. This means that some sort of flow aid is required to induce flow after the storage period. [4]

Recommendation by Jenike & Johanson, Inc.—

Jenike & Johanson recommended converting the bunker to mass flow to avoid "dead" regions and the associated fires in the bunker. Structural analysis of the existing bunker confirmed it could withstand the pressures associated with mass flow. In order to accomplish mass flow the following modifications to the existing bunker were necessary:

1. Replace the bottom section of each pyramidal hopper with new conical extensions;
2. A BINSERT®[5] (cone-in-cone design used to achieve mass flow with minimum headroom), as discussed by Carson and Dick [6,7], should be installed in the lower portion of the bunker above each hopper outlet;
3. The remaining portion of each pyramidal hopper including the valley angles, the BINSERT, the new conical extensions and the sloping bunker walls should all be lined with 1/2" thick TIVAR 88.

The complete modification is shown in Figures 7 and 8.

NSP was also given instructions regarding the quality of workmanship required to get the greatest benefit from the modifications. This included such items as grinding weldments, proper mating of flanges and proper layout and attachment procedures for TIVAR 88 liners to eliminate any unnecessary obstructions in the flow channel.[8]

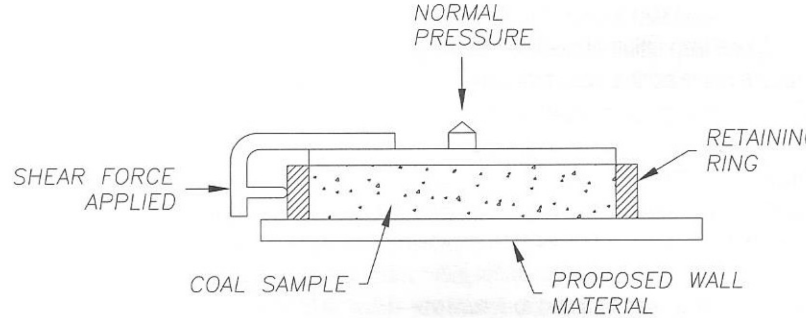

Figure 6 — Jenike Shear Tester measures the shearing force required for the coal to slide along a wall material.

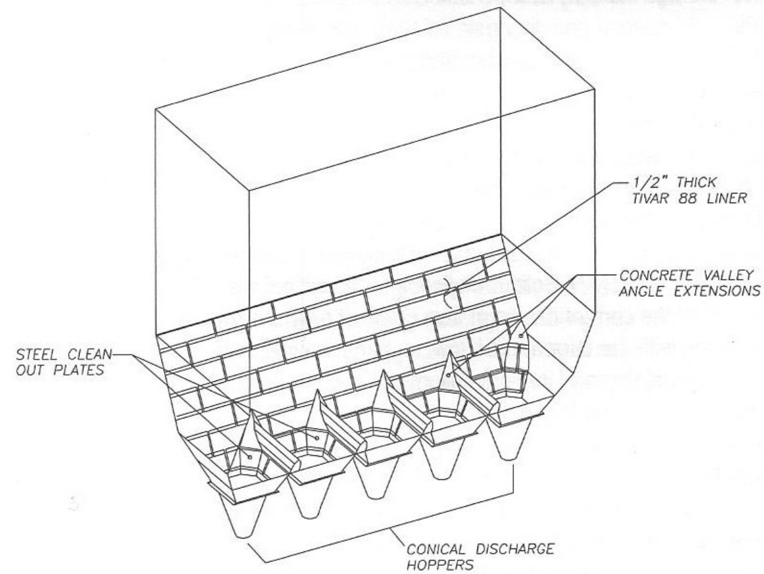

Figure 7— *Partial view of the modification as recommended by Jenike & Johanson. The sheets of TIVAR 88 are placed in a shingle (overlap) fashion to eliminate exposed horizontal seams and the vertical seams are protected by using a TIVAR "H" profile.*

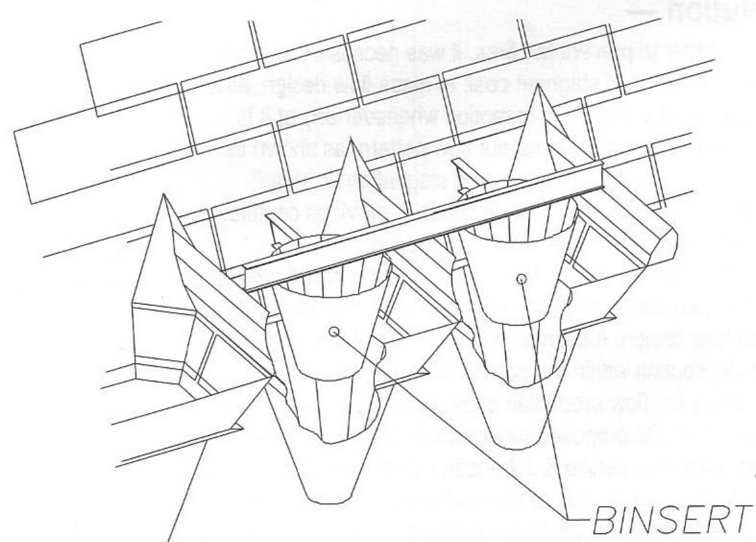

Figure 8— *Exploded view of the hopper modification, showing two hoppers fitted with the BINSERT designed by Jenike & Johanson, Inc. The BINSERTs and outer hopper cones are lined with TIVAR 88.*

Performing the modifications —

Once NSP agreed to perform the modifications recommended by Jenike & Johanson, all contractors met with the NSP engineers at the Riverside plant to lay out the plan details. This planning meeting took place on March 29, 1994, and included the NSP engineering staff, Poly Hi Solidur engineers, a certified Poly Hi Solidur installation contractor (Acrotech Services, Inc., of Bismarck, North Dakota) and NSP's Special Construction Unit from the Ironworkers Local Union 512.

The sequence of steps required to complete the modification had to be understood by all parties involved in the project since the group would be working as a team. They had 50 days (April 6 to May 26, 1994) to complete the entire modification. The sequence of procedures is outlined in the table on this page.

The ironworkers carried out the steel modification procedures and the TIVAR 88 liner installation. Poly Hi Solidur provided engineering assistance and drawings showing the exact liner layout and attachment method. The TIVAR 88 certified installation contractor supervised the entire liner installation and engineers from Poly Hi Solidur were at the job site during different phases of the installation to monitor the procedures and progress of the work.

Conclusion —

Upon completion of the modification within the scheduled time period, the bunkers were filled with sub-bituminous coal and Unit 8 went back on line. At the time of writing this paper, the bunker had only been in service for five months so limited information on the improvement is available. Preliminary reports indicate the modification was successful.

Employees in the coal yard report, prior to the modification, they would stop filling the Unit 8 bunker every day at 4 p.m. and by 3 a.m. the next day the bunker had to be charged with fuel as indicated by the level sensors in the bunker. They were able to obtain 11 hours worth of fuel from the bunker before it required refueling.

Since the modification, the coal yard stops filling the bunker at 4 p.m. and it does not require refueling until 10 a.m. the next day, or 18 hours later. These statistics indicate a "live" capacity improvement of 64% over the original design.

More information on the improvement modification will be available in November, when NSP does a thorough inspection of the bunker.

MODIFICATION PROCEDURE SEQUENCE

1. Sandblast interior steel and Gunite surfaces
2. Frame the valley angles with wooden forms and fill with cement.
3. Remove the existing standpipes.
4. Remove the lower 10 ft. of the five pyramidal shaped hoppers.
5. Weld four new conical shaped hoppers to the remaining portion of the pyramidal shaped hoppers.
6. Start lining the sloping, high-friction Gunite walls with TIVAR 88, which is fastened directly to the gunite using concrete expansion bolts.
7. Raise the five new BINSERTS (lined with TIVAR 88) into the bunker through the remaining opening in fifth hopper section.
8. Install the steel support beams and attach the BINSERTS.
9. Weld the fifth new conical shaped hopper to the last pyramidal shaped hopper.
10. Continue lining the concrete valley angles, the pyramidal shaped upper hopper sections, and the new conical shaped lower hopper sections with TIVAR 88. (The TIVAR 88 was fastened to the steel substrate with a weld washer attachment system.)

[1] Marinelli, J. and Carson, J.W.: "Solve Solids Flow Problems in Bins, Hoppers, and Feeders"; *Chemical Engineering Progress*, May 1992, pp. 22-28.

[2] Jenike, A.W.: "Storage and Flow of Solids," Bulletin 123; University of Utah, Engineering Experiment Station, Nov. 1964.

[3] McAtee, K., Bermes, S. and Goldberg, E.: "TIVAR 88 Provides Reliable Gravity Discharge from Coal Storage Silos," *bulk solids handling*, Vol. 11 (1991) No. 1, pp. 79-83.

[4] Jenike & Johanson, Inc., Report 932930-1: "Modifications to Unit 8 Coal bunker, Northern States Power Riverside Plant," April 19, 1994.

[5] Johanson, J.R.: "Blending Apparatus for Bulk Solids"; US Patent # 4,286,883, Sept. 1, 1981.

[6] Carson, J.W. and Dick, D.S.: "How Bin Retrofits Can Correct Flow Problems," presented at the AIChE Spring National Meeting, Houston, April 4, 1989.

[7] Carson, J.W.: "North American Advances in the Design of Silos, Bins and Hoppers," *bulk solids handling*, Vol. 11 (1991), No. 1, pp. 37-44.

[8] Steppling, K. and Hossfeld, R.J.: "Ultrahigh Molecular Weight Polyethylene Abrasion Resistant Liners Facilitate Solids Flow in Hoppers," *bulk solids handling*, Vol. 5 (1985), No. 5, pp. 1049-1052.