

Fuel-handling considerations when switching to PRB coals

Through properly planned upgrades and equipment changes, the Rush Island plant staff was able to minimize fuel-handling problems after a switch to PRB coal. Substantial reductions in fuel cost more than paid for the upgrades

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Powder River Basin (PRB) coal contains low amounts of sulfur, and costs less on a delivered-Btu basis than many eastern coals. Fuel saving can be on the order of 30 to 40%. Because of these environmental and economic benefits, many powerplants have made the switch from eastern to PRB coals, and many more conversions are planned (see box, p 56).

However, fuel-handling problems may arise at plants making the switch—and handling problems that existed prior to the conversion can be worsened—because of a change in flow properties

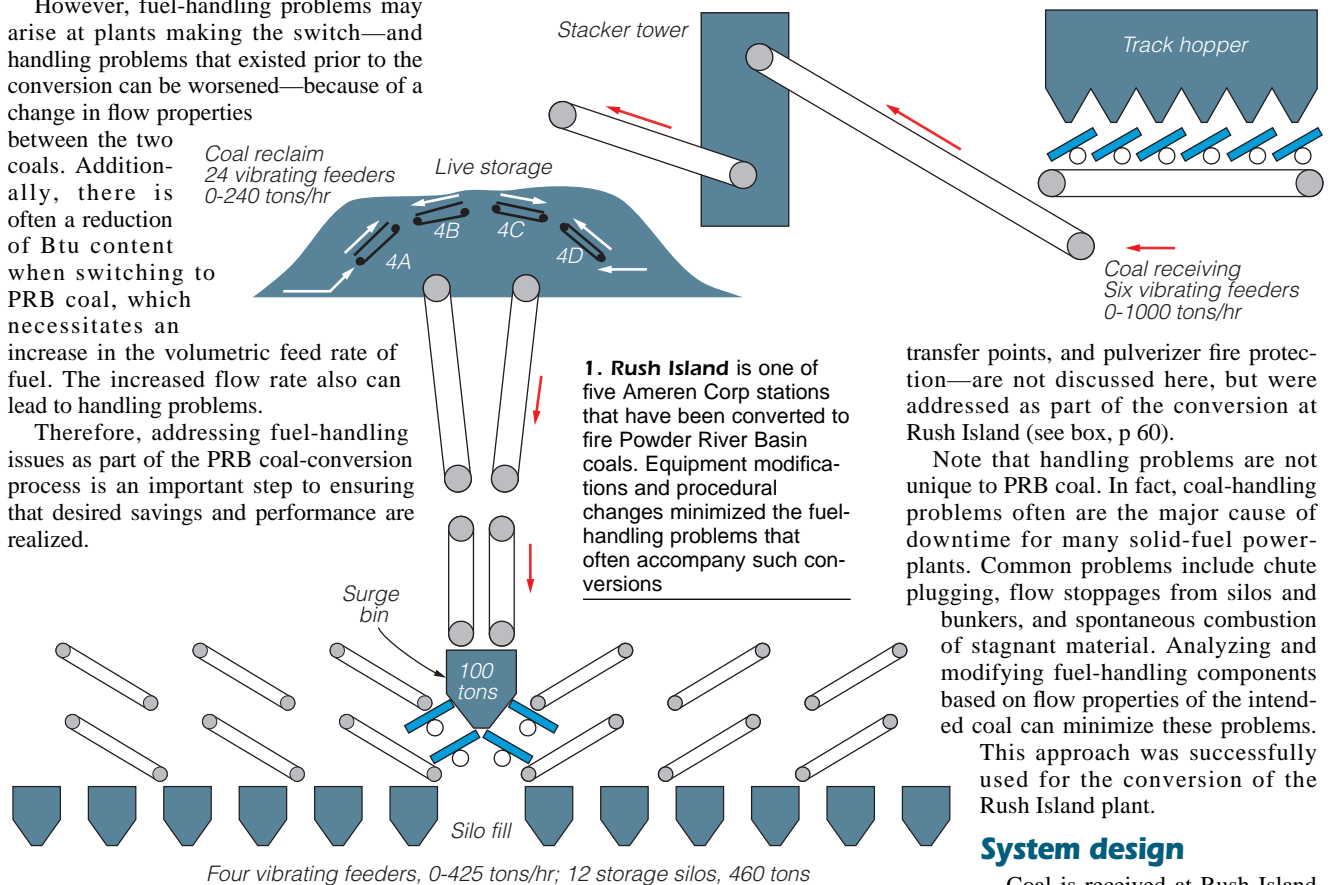
between the two coals. Additionally, there is often a reduction of Btu content when switching to PRB coal, which necessitates an increase in the volumetric feed rate of fuel. The increased flow rate also can lead to handling problems.

Therefore, addressing fuel-handling issues as part of the PRB coal-conversion process is an important step to ensuring that desired savings and performance are realized.

Conversion veterans

Ameren Corp, St. Louis, Mo, has completed PRB conversions at five of its eight coal-fired powerplants. Two plants—Meramec and Sioux—were converted to burn a blend containing up to 70% PRB coal. Three—Labadie, Newton, and Rush

Island—were converted to burn 100% PRB coal. The behavior of PRB coal in general, and the fuel-handling system at the Rush Island plant specifically, will be discussed in this article. Additional plant issues that need to be addressed when converting to PRB coal—including boiler-fan capacity, dust control at handling-system



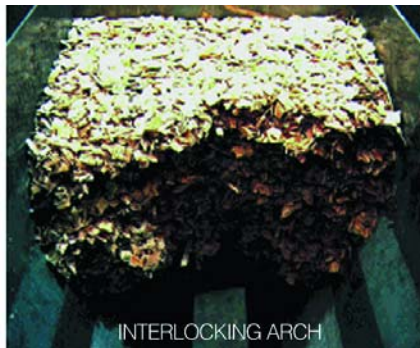
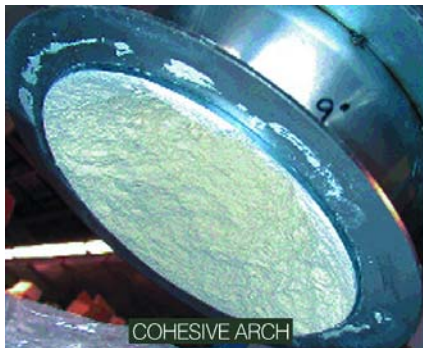
transfer points, and pulverizer fire protection—are not discussed here, but were addressed as part of the conversion at Rush Island (see box, p 60).

Note that handling problems are not unique to PRB coal. In fact, coal-handling problems often are the major cause of downtime for many solid-fuel powerplants. Common problems include chute plugging, flow stoppages from silos and bunkers, and spontaneous combustion of stagnant material. Analyzing and modifying fuel-handling components based on flow properties of the intended coal can minimize these problems.

This approach was successfully used for the conversion of the Rush Island plant.

System design

Coal is received at Rush Island



2. Two types of arching can occur when an obstruction in the shape of an arch or a bridge forms above the outlet of a hopper and prevents coal flow. A cohesive arch is when particles pack together to form an obstruction (left); an interlocking arch is where the particles mechanically lock to form the obstruction (right)

by rapid discharge, bottom-dump rail cars (Fig 1). It is unloaded with six vibrating feeders, each capable of feeding 1000 tons/hr of PRB coal. The conveying system can stack out PRB coal at a rate of 4000 tons/hr. All coal received is stacked out through a tower and a radial-stacking boom conveyor to a live-storage, kidney-shaped pile.

From live storage the coal can be moved, as required, to long-term storage for compaction and future use. Coal on the live-storage pile is typically reclaimed within five days.

Reclaimed coal enters the conveying system through one of 24 underground hoppers with vibrating feeders. The feeders, and four conveyors which the feeders serve (six feeders per conveyor), are arranged in a kidney shape to conform to the shape of the live-storage coal pile. A pneumatic signal on the vibrating feeders controls the feed rate by changing the posi-

tion of an eccentric weight, which changes the vibration stroke of the feeders. Each feeder can deliver 0-240 tons/hr.

Coal discharged from the feeders is loaded onto one of the four reclaim conveyors (4A, 4B, 4C, or 4D), which are sized for 700-ton/hr operation. The 4A and 4B conveyors discharge into a common transfer chute, which loads coal onto inclined conveyor 5A. The 4C and 4D reclaim conveyors likewise discharge coal onto inclined conveyor 5B. The inclined conveyors deliver coal to a transfer house and through a transfer chute to the 6A and 6B conveyors. These conveyors move the coal inside the plant to a 100-ton surge bin and the silo-fill conveying system.

Coal is fed from the surge bin by variable rate (0-425 tons/hr) vibrating feeders, which are of similar design to the reclaim feeders. The silo-fill system comprises parallel, cascading conveyor lines for each of

the two generating units. These conveyors operate by feeding the first of the 400-ton silos in line (A and B), the eventual filling of which causes coal to continue to the second silos (C and D). Once the second silos are full, coal continues to the last silos (E and F), which are mounted on load cells. As these last silos fill, a 4- to 20-mA signal is sent back to trigger the pneumatic signal on the surge-bin vibrating feeders to decrease or stop coal flow.

Rush Island review

Several historical problems were known to exist with the coal-handling system at the Rush Island plant. Additionally, the reduction in Btu content from switching to PRB coal would require an increase in the volumetric feed rate, and some portions of the handling system were not capable of operating at this increased rate.

To address these problems, Jenike & Johanson Inc, Westford, Mass, conducted a review of the known and predicted problem areas before specific changes were made. Two of the most common flow problems experienced in an improperly designed bunker, silo, or bin (hereafter collectively referred to as silo) are no-flow and erratic flow.

■ **No flow** from a silo can be caused by either arching (bridging) or rat-holing. 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 coal discharge. It can be an interlocking arch, where the particles mechanically lock to form the obstruction, or a

PRB Coal Users Group to convene in March

The large number of US powerplants that have switched to Powder River Basin (PRB) coal has prompted the formation of the PRB Coal Users Group. Its objective is not to lobby for increased burning of the low-sulfur fuel, but only to promote its safe, efficient, and economic use. Chairman Randy Rahm, director of coal technical services for Western Resources Inc, Topeka, Kans, notes that PRB coal presents special fuel-handling concerns, many of which can lead to serious safety considerations.

For example, PRB coals are particularly vulnerable to spontaneous combustion of stagnant material, which can result from flow stoppages in silos and bunkers. The hazard has prompted the National Fire Protection Assn (NFPA) to state in its 1997 Standard for Pulverized Fuel Systems that new coal silos

and bunkers must be designed for mass flow—rather than funnel flow—as a preventive measure. In order to achieve mass flow, two conditions must be met:

(1) The sloping hopper walls must be steep enough and low enough in friction for the particles to slide along them.

(2) The hopper outlet must be large enough to prevent arching.

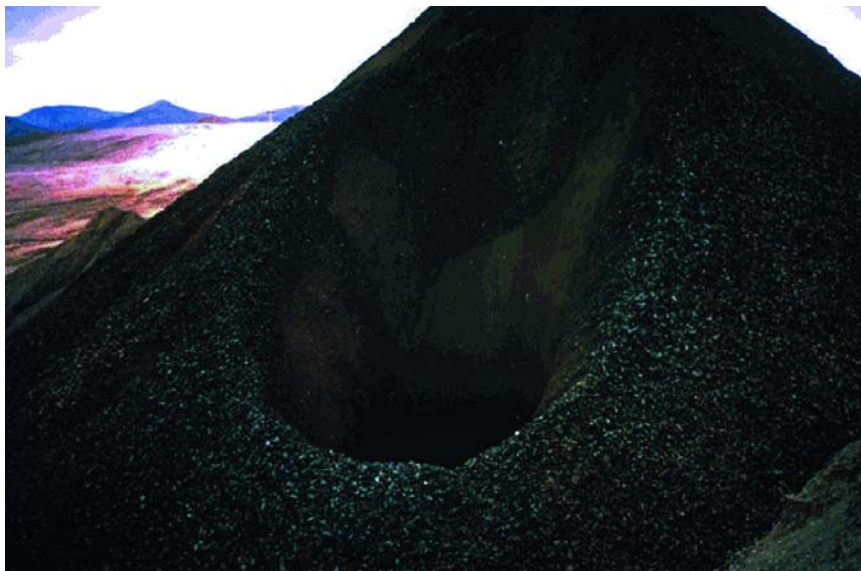
Next meeting of the PRB Coal Users Group will be March 19-22, 2002, in Ameren Corp's home city of St. Louis, Mo. The meeting will be collocated with the *Electric Power 2002 Conference & Exposition*. POWER is proud to serve as the official magazine of this important trade association. For more information on the PRB Coal Users Group and its next meeting, visit www.PRBcoals.com.

In memoriam

In October, the PRB Coal Users Group lost a highly respected colleague and a great friend. Mike Brouhard, who managed the Tecumseh Energy Center for Western Resources Inc, Topeka, Kans, died in a tragic highway accident.

Mike wrote the article "Tecumseh Energy Center celebrates 75th birthday" (POWER, November/December 2000, p 85), and his plant recently was nominated for the 2002 PRB Plant of the Year Award. His steadfast priority was the safety of the Tecumseh plant and all of its personnel. Tecumseh is a small plant with a small budget, but somehow Mike was able to find the resources and the time to implement the best technologies in dust control, fire detection, and fire suppression.

A memorial has been established with the Mike Brouhard Family Scholarship Fund c/o Wanamaker Woods Church of the Nazarene, 3501 Wanamaker Rd, Topeka, Kans 66614.



3. Rat-holing is another mechanism that stops coal flow in a silo. The PRB coals, because of their cohesive strength, are particularly susceptible

cohesive arch (Fig 2). 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. Rat-holing can occur in a silo where coal 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 will therefore stop (Fig 3).

■ **Erratic flow** is the result of an obstruction alternating between an arch and a rat-hole. A rat-hole may fail because of 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 or a vibrator. While some coal discharges as the rat-hole collapses, falling material often gets compacted over the outlet and forms an arch. This arch may break because of a similar external force, and material flow resumes until the flow channel is emptied and a rat-hole forms again.

While flow stoppages of any coal can be costly, stoppages of PRB coals, which are more prone to spontaneous combustion, can be especially dangerous. If flow takes place through a channel within the silo, the material outside of the channel may remain stagnant for a long time (depending on how often the silo is completely emptied), increasing the likelihood of combustion.

Collapsing rat-holes and arches can cause silos to shake or vibrate. They also can impose significant dynamic loads that cause 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. The PRB coals are particularly vulnerable to spontaneous combustion of stagnant material, which can result from flow stoppages in silos and bunkers. To counter the hazard, coal silos and bunkers must be designed for mass flow (left), rather than funnel flow (right)

Funnel-flow no, mass-flow yes

No flow and erratic flow often occur in silos where flow takes place through a channel formed within stagnant material. This is referred to as a funnel-flow pattern, in which some material moves while the rest remains stationary during discharge from the silo (POWER, November/December 2000, p 53). Funnel flow occurs when the sloping hopper walls of a silo are not steep enough, and not 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 acceptable only when all of the following conditions are met:

■ The material being handled consists entirely of coarse particles—typically 0.25 in. in diameter or larger.

■ The material is free flowing; particles

do not stick to each other.

■ The particles are non-degrading—for example, spontaneous combustion does not occur when particles are stagnant for an extended duration.

■ Particle segregation is not a concern.

Most coals, especially PRB coals, do not meet these conditions. The PRB coals tend to be friable, resulting in a large amount of fines. And they also can be very cohesive, particularly at an increased moisture content. As mentioned earlier, spontaneous combustion also is a major concern with PRB coals. For these reasons, flow-related problems often occur in funnel-flow silos, so mass-flow silos should be used whenever possible.

Mass flow is defined as the flow pattern, whereupon withdrawal of any material, all of the material in a silo moves (Fig 4). Mass flow occurs when particles slide along sloping hopper walls during discharge. Mass flow eliminates rat-holing 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: (1) The sloping hopper walls must be steep enough and low enough in friction for the particles to slide along them; and (2) the hopper outlet must be large enough to prevent arching.

Hopper angle and smoothness.

How steep and how smooth must a hopper surface be? That depends on the friction that develops between the particles and the hopper surface. This friction can be measured in a laboratory using an ASTM-described wall-friction test, in which a small sample of bulk solid is placed in a test cell and slid along the wall surfaces of interest—for example, stainless steel with No. 2B, No. 1, or mill finish, or polyethylene liners.

As various forces are applied perpendicular to the cell cover, the shear force is measured. Results of the test, which originally was developed by Dr A W Jenike at the University of Utah, provide design criteria for achieving mass flow in new hopper and bunker installations, and are invaluable in evaluating retrofit options for liners, coatings, and polished surfaces with existing installations.

■ **Hopper outlet size.** The second requirement for mass flow is that the outlet must be large enough to prevent arching. As discussed above, 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.)

■ Cohesive arches can be analyzed by

determining the cohesive strength of the material. First the flow function of the material—the cohesive strength vs consolidating pressure—is measured through laboratory testing. Tests are conducted using an ASTM-described direct shear tester. 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. The measured property directly relates to a material's ability to form a cohesive arch or a rat-hole. Once the flow function is determined, minimum outlet sizes to prevent arching or rat-holing can be calculated through a series of design charts, which also were published by Dr Jenike.

Feeder design

In addition to ensuring that reliable flow takes place in the hopper, it also 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 smaller active flow channel, regardless of the hopper design. It is therefore imperative that a feeder be able to continuously withdraw material from the entire outlet of the hopper. This feature will allow mass flow to take place in the hopper. It also will reduce the potential for rat-holing if a funnel-flow pattern exists, by keeping the active flow channel as large as possible.

As an example, when using a slotted outlet, it is required that the feeder capacity increase in the direction of flow. When using a belt feeder, this increase in capacity is achieved by using a tapered interface. The increasing capacity along the length is achieved by the increase in height and width of the interface above the belt.

Chutes and conveyors

Another key to successful PRB-coal conversion is that chutes must be designed to prevent plugging, while minimizing surface wear, particle attrition, and dust generation. Minimization of attrition—or fines generation—is especially important with PRB coals, given their friable nature, because attrition, when combined with high moisture contents, makes chute pluggages more likely.

By far the most common problem with chutes is plugging at impact points, such as after a free fall or where the material stream changes direction. Chutes must be sufficiently steep and smooth to permit sliding and clean-off of the highest-friction material that they will handle. However, chutes should be no steeper than required in order to minimize velocities, and thereby reduce wear and dusting.

Minimizing free-fall heights and changes in the direction of material flow also helps to reduce chute wear, as well as attrition, dusting, and fluidization of fine materials. Other keys to reducing dusting are keeping the material in contact with the

Dry fogging system controls coal dust at Joppa station

Dust control at handling-system transfer points is another issue aggressively being managed by Ameren Corp (St. Louis, Mo) powerplants firing Powder River Basin (PRB) coal. For example, the 1100-MW Joppa station, owned by Ameren subsidiary Electric Energy Inc, Joppa, Ill, has switched to an innovative dry fogging system, which controls dust by agglomerating the airborne dust particles to micron-sized water droplets. According to the system's supplier, Dust Solutions Inc, Portland, Ore, the wetted dust particles simply fall back into the fuel-stream by gravity because of their increased particle mass.

Unlike standard water-spray systems, dry fogging consumes little water and does not wet the fuel—only the airborne dust. The system also is lower in operating cost, the supplier

reports, compared to chemical-based systems, and lower in capital cost compared to conventional dust-collection systems. At PRB coal-fired plants, the technology can be used to reduce explosion hazards at conveyor transfer points, truck and rail dumps, reclaim feeders, crushers, and wind-screens (figure).

Fog containment. Both the dust particles and the fog droplets have to be contained in enclosures so that agglomeration can occur. With conveyor-transfer points, there must be sufficient room for the fog to fully develop, particularly in the receiving-belt area. In addition, the tightness of skirt boards must be maintained, conveyor covers must be in place, and inspection doors must be closed to ensure efficient operation of the dry-fogging system.



Dry fog is expanded externally and away from nozzles at this feeder-to-conveyor transfer point to control PRB coal dust, and thus reduce explosion hazards

chute surface, concentrating the material stream, and keeping the velocity through the chute to as near constant as possible. By following these guidelines, the amount of dust generated at a transfer chute can be reduced by orders of magnitude, or even eliminated completely.

Making the switch

Changes in some of the coal characteristics required an increase in the coal usage rates at Rush Island after the conversion. In switching from the previously used Illinois coal to PRB coal, a reduction in Btu content of approximately 20% was expect-

ed. In addition, the bulk density was expected to be approximately 10% less for the PRB coal. These factors combined to yield a predicted minimum increase in coal usage of 25%, on a volumetric basis.

Such an increase required that equipment be capable of handling a higher material flow. First, the conveyor speeds needed to be increased. Second, the transfer chutes would be operating fuller, and as the cross-section of a chute becomes fuller, the potential for pluggage increases. A third consequence of the increased flow rate is that silos would be subjected to more frequent filling and emptying, so their feeders

would have to operate at higher speeds. A significant arching potential with the PRB coal would therefore have a greater effect on the performance of the system. Finally, the higher risk of spontaneous combustion with PRB coal required that reliable flow be achieved from the silos and, at the very least, stagnant material within the silos be minimized.

Flow property tests were conducted by Jenike & Johanson Inc on samples of three types of PRB coal. These tests showed that the coal, particularly at moisture contents nearing saturation (as was likely, because the plant's pile storage was outside), was cohesive and capable of forming a stable rat-hole in a funnel flow silo. This result also indicated that the PRB coal was capable of arching, more so in funnel flow than in mass flow because of its cohesive strength. There also was a significant gain in cohesive strength measured as the time of storage increased, indicating an increased likelihood for arching and rat-holing if feed from a silo was stopped for an extended period. The coal was noted as being quite frictional too, so to obtain mass flow, a steep hopper angle would be required, using 304 stainless steel sheet with a No. 2B finish.

Better results were obtained with one type of ultra-high molecular weight (UHMW) polyethylene surface, although there was some concern with using this surface because of the risk of spontaneous combustion. Finally, minimum chute angles to ensure flow after impact tended to be steep, indicating the need to limit velocities, and therefore impact pressures, while keeping the chute surfaces steep enough to avoid buildup and pluggages.

Modifying chutes

An analysis of the Rush Island handling system, in light of the predetermined PRB coal flow properties, showed potential problems with several of the transfer chutes, as well as with the 100-ton surge bin and the storage silos. Large vertical drop heights resulted in opportunities for chute buildup and pluggage. In addition, the outlet sizes of the surge bin and silos were smaller than the minimum outlet dimensions calculated for the worst handling samples of PRB coal to avoid the potential for both arching and rat-holing.

A review of operating history by Ameren Corp showed that existing fuel-handling problems included chute pluggages at transfer locations, arching within the silos, and flow stoppages leading to spontaneous combustion. Based on this history, and an assessment of the best return on investment, the problems with the transfer chutes were addressed first, through equipment modifications. The modifications included changes to the chute geometries to reduce velocities and impacts, while ensuring their cross-sectional area would not be over-filled at the

required feed rates.

One chute in particular that required modifications is contained within the stacker tower, and begins at the termination of conveyor No. 2 at its top. At the base of the tower, conveyor No. 3 is used to stack coal onto the pile. This conveyor can rotate ± 90 -deg horizontally and ± 15 -deg vertically to reach the farthest extents of the pile. The chute design that was implemented began with a vertical section at its top, onto which coal impacts after leaving conveyor No. 2. Coal then drops to an inclined section, whose slope was chosen to ensure clean-off after impact. The stream slides on this section and becomes airborne. It impacts a second vertical section, which is attached to an inclined section below to reverse the stream's direction. The coal finally drops to another inclined section, which is attached to and rotates with conveyor No. 3 to direct the stream onto it. The vertical sections of this arrangement were lined with Mangabrazee, a surface well-suited for impact that prevents both abrasive and surface fatigue wear.

The Mangabrazee was supplied by Baldwin International, Solon, Ohio. The inclined sections were designed using 304 stainless steel sheet with a No. 2B finish, to ensure flow after impact. This arrangement results in a stream with well-controlled coal velocities, because of nearly constant coal contact with chute surfaces, along with low impact pressures and no buildup caused by minimal drop heights. Other transfer chutes in the coal-handling system were analyzed and modified in a similar manner.

Spontaneous combustion

The test results indicated that the existing hopper and feeder designs would experience arching of PRB coal within the silos and surge bin only at the highest moisture contents. As a result, Ameren opted not to make changes as part of the initial conversion. Problems that arose were to be handled with "brute force" methods of breaking arches and clearing rat-holes by hand.

But the problem of spontaneous combustion caused by stagnant coal still had to be addressed. Although this problem was historically the least frequent in occurrence, it would be more likely after the conversion to PRB coal, and it was potentially the most expensive. For prevention, a change in operating procedures was made, whereby the silos are periodically drawn down to low levels once every three to five days. This procedural change reduced the chance of producing a hot spot because of coal stagnation.

Stagnation problems still can be encountered because of forced outages of mills or conveyors in which significant quantities of coal remain in a silo. To monitor this situation, an infrared thermometer

is used to take temperature readings of the outside surfaces of the silos. The readings are normally taken once per shift to determine if a hot spot is developing.

If a hot spot does develop, a carbon monoxide monitor or odor detector will then show if combustion is occurring. In this case, a chemical agent known as F-500 is applied with a fire hose to combat the combustion. Originally known as "Fuel Buster," F-500 has been used by firefighting agencies to combat liquid hydrocarbon fires since the 1980s. Its application to powerplants began in the 1990s; it typically is diluted to a 1-3% solution, and applied to the water stream through a variety of methods: eductors, proportioners, premixing, or batch-mixing. Advantages of using F-500 include fast extinguishing times, and rapid reduction of heat and smoke. The product, available through Hazard Control Technologies Inc, Fayetteville, Ga, is environmentally safe, 100% biodegradable, and requires no special permits for its purchase, transportation, or handling.

Edited by Robert Swanekamp, PE