Managing silo, bunker, and dust-collector fires

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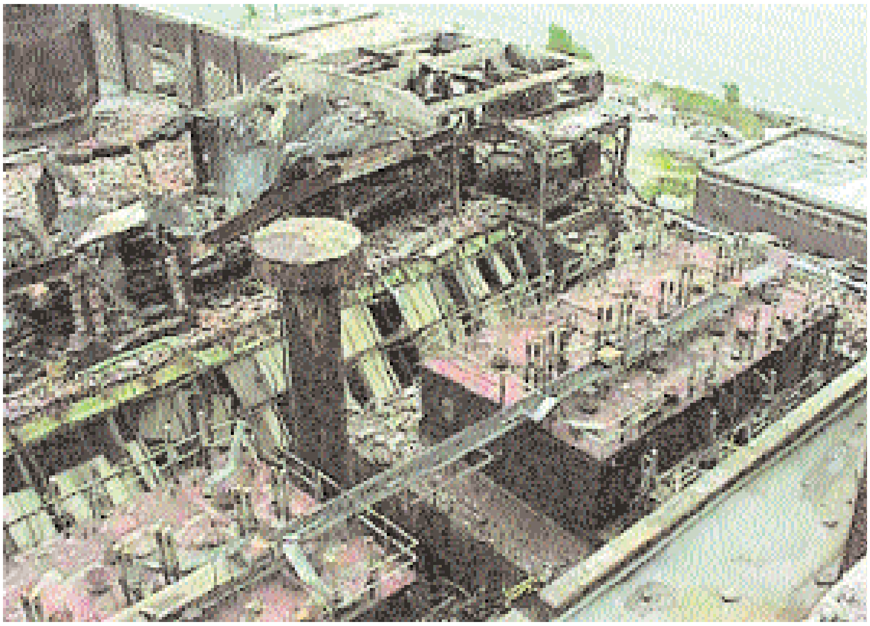
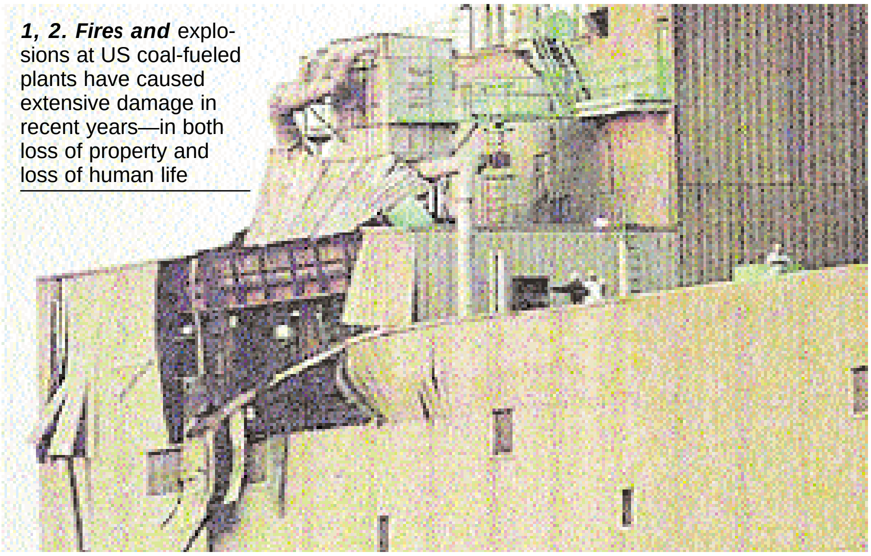
Coal fires at powerplants happen far too frequently these days. Despite a century of industry experience, opinions vary on how to prevent the fires from occurring, and how to extinguish them if they do





1, 2. Fires and explosions at US coal-fueled plants have caused extensive damage in recent years—in both loss of property and loss of human life

Coal fires at powerplants can cause serious destruction. If handled incorrectly, the results can be catastrophic, in both damage to powerplant assets and the loss of human life (Figs 1, 2).

One of the coal-fired plants operated by Western Kentucky Energy Corp (WKE), Henderson, Ky, recently experienced a silo fire that resulted in the loss of valuable time during a busy outage (see box, p 54). Fortunately, the outcome was not more serious. But the entire chain of events, beginning with the circumstances that preceded the fire through the incident's resolution, points to a serious problem in the power industry.

WKE encourages an aggressive approach to safety, so the company spent a lot of time and effort investigating this incident. What was learned from the experience at this plant prompted WKE to dig even deeper. It found that, throughout the industry, insufficient information and inadequate education have created serious misconceptions regarding how best to address coal-plant fires. The following article is intended to educate you, and encourage you to closely examine your own plants.

Strike one

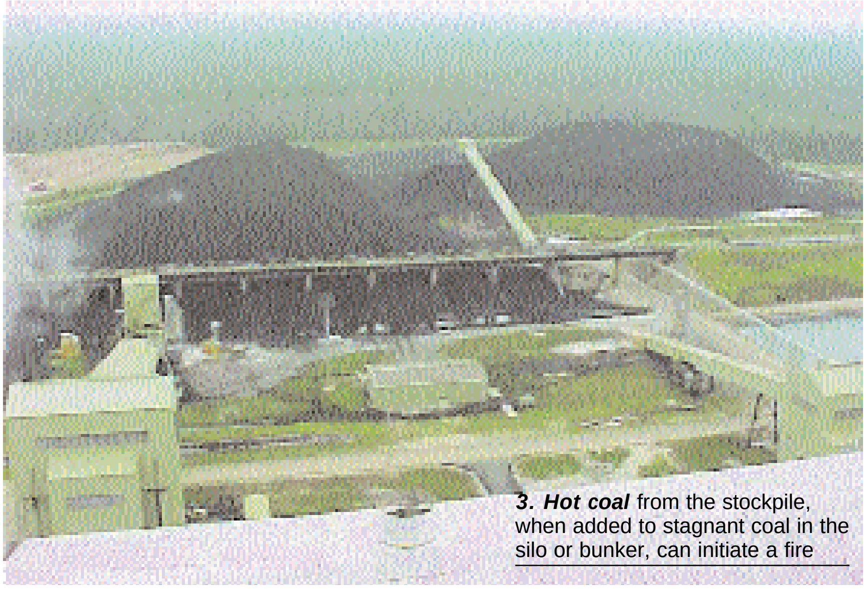
In April, the plant operated by WKE was scheduled for a 30-day outage. Four days before the unit was to be shut down, it experienced the first of two unrelated coal-fire incidents. In the first, the conveyor belt system caught fire near the barge unloader. Coal and thiosorbic lime had been carried on the conveyor in the days prior to the fire.

A root-cause analysis determined that the fire was sparked when a driving rain reached lime residue in the dust collector, producing an exothermic reaction. The belt was not running at the time the fire occurred, but the hot lime is believed to have ignited coal dust in one of the bags, or in coal-dust accumulations in the fabric filter.

Most of this plant's dust collectors are

Powerplant operators

Western Kentucky Energy Corp (WKE) generates electricity at four powerplants owned by Big Rivers Electric Corp, Henderson, Ky, through a 25-yr lease agreement. WKE is a wholly owned subsidiary of LG&E Energy Corp, Louisville, Ky, and is not affiliated with Big Rivers Electric Corp.



3. *Hot coal* from the stockpile, when added to stagnant coal in the silo or bunker, can initiate a fire

equipped with CO_2 fire suppression systems and most of the conveyors are protected by water-deluge systems. However, the equipment located near the barge unloader was purchased from a different supplier and is not protected by a suppression system. Portions of the two belts connected to the transfer point where the fire started were burned, resulting in the destruction of 725 ft of conveyor structure and approximately 1200 ft of belt. More than two weeks of repairs were needed to return the conveyor to service.

Strike two

The second coal-fire incident occurred in a coal-storage silo. Two mistakes were made prior to shutdown that contributed to this incident. First, the silo was not emptied in anticipation of the outage, so approximately 300 tons of coal remained inside. Second, the reclaimer picked up coal from a hot spot in the stockpile, and loaded the hot coal into the silo, just a half-hour before the shutdown began.

Initially, the appropriate personnel were not notified of the hot-silo condition. Once informed, they began monitoring carbon monoxide (CO) levels and temperature, using a probe lowered into the silo through a conduit. The temperature on day seven of the outage was 107F. By 8:00 a.m. on day nine, the temperature was 154F. By 11:00 a.m. that day, the temperature had climbed to 171F, indicating that the event was at a critical stage. Corrective actions being considered were to:

- Purge with nitrogen, which was not readily available.

Danger lurks in the dust

A deflagration is a fire characterized by a rapidly propagating flame front at a velocity less than the speed of sound. This is exactly what happens when coal dust explodes.

The particle size of coal dust on the roof beams, on the inside walls of silos or bunkers, and in the conveyor areas above the coal storage is very fine. The finer the dust, the lower the ignition energy required for it to explode.

The ignition energy required for explosion also drops as ambient temperature increases. On hot summer days when temperatures on top and inside the plant reach more than 100F, the energy required to ignite coal dust is significantly reduced.

Explosibility index

The explosibility of coal dust is measured using the Kst index. Bituminous coal has a Kst value that varies from less than 80 to 130 bar m/s. Subbituminous coal—such as Powder River Basin (PRB)—has a much higher Kst value, varying from less than 120 to greater than 200 bar m/s. In other words, the explosibility of PRB coal can be up to two times that of bituminous coal. Clearly, coal dust must be respected, or it will destroy your plant!

Note: The Kst values provided by fuel suppliers are approximate. If you want to know for certain the Kst value of your dust, have it tested. Fike Corp, Blue Springs, Mo, a test provider, says it is best to test during the hottest, driest time of the year, to obtain the highest Kst value.

Dysfunctional dust collectors

It's important to know if the vent area on your dust collector is sufficiently sized to vent the pressure wave that would be created in a coal-dust explosion. Without adequate vent area, an explosion in the collector could fragment your collector, or propagate back into your system since most dust collectors do not have backdraft dampers.

The majority of pre-1980 dust collectors installed in the utility industry were designed for bituminous coals, and are completely inappropriate for subbituminous (or PRB) coals. Two common problems are improperly located, and improperly programmed, hopper-level control switches.

PRB coal dust cannot be stored in a dust collector hopper for any period of time. The dust collector must be pulsed and purged everyday. If PRB coal dust is left in the dust collector and it is shutdown, the dust could begin to smolder. When the dust-collector fan is started with smoldering coal dust in the hopper, it will explode.

Another common problem with dust collectors is that their explosion vents discharge to the inside of a building. With this arrangement, powerplant designers inadvertently designed a bomb! If a primary explosion is vented inside a building, and if there is coal dust on the beams and floors, there will be a serious, secondary explosion inside the building—where employees tend to be found.

If you have an internally discharged explosion vent in your plant, you need to identify it and redirect it outside the building. Also, do not obtain a dust-collection system from an engineering firm that doesn't specialize in these systems. Over the past 10 years, one firm, Air Cure Inc, Minneapolis, Minn, has designed and engineered the majority of new and upgraded dust-collection

4. Trained personnel can prevent fires from occurring, keep automatic suppression systems properly maintained, and quickly extinguish fires in the incipient stage

systems in the US utility industry. If purchasing a new system, buy the dust collector, ductwork design, pneumatic transport system, and dust-disposal system from the same company.

Fire protection systems in dust collectors are typically a dry-pipe system with some type of head with a fusible link. A temperature sensor sets off the fire-suppression system and the dust collector continues to burn until the fusible link melts and water starts to flow, floating the burning coal dust up into the bags. Extra care must be taken to avoid opening the dust collector while the floating dust is still burning or water followed by fire can pour out and endanger personnel. The majority of the time, water does *not* extinguish the fire in the first few minutes. The fire usually burns until it runs out of bags and coal dust.

CO_2 blanketing systems are also used for fire suppression in dust collectors. The CO_2 acts the same as it does in a silo of coal and slows down but does not completely extinguish the fire. The dust collectors are not a sealed unit and have natural drafts that remove the CO_2. Depending on the activation method, if a fire develops, these systems could disperse the dust and cause an explosion.

A properly fire-protected dust collector has open heads and CO monitors along with thermal sensors. When the CO monitor detects a fire, its alarm sounds, all equipment associated with the dust collector is shutdown, and plant personnel should inspect the outside of the dust collector.

Never open a door or any access to the inside of a dust collector that is on fire or may be on fire. There have been numerous incidents where plant personnel opened a door of a dust collector that was on fire, and thereby created a draft that dispersed coal dust and caused a devastating explosion.

If a fire is indicated by a laser pyrometer, thermal imaging camera, or the smell of burning coal, you should manually trip the deluge system containing water with F-500 metered into the suppression system. The F-500 will break the surface tension of the water and will properly wet the dust, not float it. Bags will wet much faster and there will be less damage to the dust collector, compared to using water alone. In a recent fire and explosion that occurred in a dust collector equipped with an F-500 suppression system, only 160 out of 686 bags were destroyed

- Purge with CO_2, which was available at the feeder under the bunker.
- Withdraw the coal using a vacuum truck and hose, which is labor-intensive and messy.
- Flood with water; the silo is equipped with a water deluge system, but this option is messy.

Corrective action

Of those options, a CO_2 purge initially seemed best, so the plant began establishing a CO_2 blanket. But subsequent discussions with members of the American Society of Mechanical Engineers (ASME) Research Committee on Powerplant & Environmental Chemistry pointed to two significant concerns: (1) CO_2 was not an effective means of putting out the fire; and (2) the action could produce high CO levels or even explosions.

When these concerns were passed along to the plant manager, he quickly checked CO levels. Sure enough, they already had risen in the tripper room above the silo.

Engineers stopped the CO_2 purge and initiated a different option: withdrawing the coal using a vacuum truck and hose. All of the coal was wetted down with water and slowly removed over the next three days, with no significant problems.

The successful resolution of this hot-silo incident brought a sigh of relief, but also some unanswered questions—questions that, the company discovered, are resonating throughout the power industry. The ASME Research Committee on Powerplant & Environmental Chemistry includes some of the most experienced people in the field, yet even its members do not completely agree on how to best address coal-plant fires. Based on the WKE incident and subsequent research, three conclusions were drawn:

1. Coal fires at powerplants happen far too frequently.

2. The potential for disaster is significant.

3. More education and training are needed on how to prevent these fires from occurring, and how to extinguish them if they do.

5. Secondary explosions typically cause the greatest amount of property damage, so initial response to a fire incident is critical

F-500 for suppression

One advanced tool in coal-fire suppression is the chemical agent known as F-500, supplied by Hazard Control Technologies Inc, Fayetteville, Ga. Most powerplants are equipped with water-deluge systems in their dust collectors, silos/bunkers, and tripper rooms, as well as over their conveyors. Wetting and chemical agents can be added to these deluge systems to increase their effectiveness, but there are significant differences between wetting agents, foams, and the relatively new product, F-500:

- Wetting agents rely solely on reduction of the surface tension of water. Coal and other fuels can float on top of these agents, and remain burning.
- Foam products rely on two mechanisms—they reduce the surface tension of water, and they establish a blanket that deprives the fire of oxygen.
- F-500 works by three mechanisms. Like wetting agents and foams, it reduces the surface tension of water. In addition, it forms "micelles," which encapsulate the fuel. The F-500 molecules are polar (hydrophilic) on one end and non-polar (hydrophobic) on the other, with enough distance between to allow the ends to act independently of each other. This construction creates negatively charged micelles or "chemical cocoons" that repel each other. In the third fire-suppression mechanism, F-500 interrupts the free-radical chain reaction by absorbing the energy of the free radicals during collisions. Thus it reduces the energy of combustion in a coal fire.

Originally known as "Fuel Buster," F-500 has been used by firefighting agencies to combat liquid hydrocarbon fires since the1980s. Its application to powerplants began in the 1990s. The product typically is diluted to a 1-3% solution, and can be 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, rapid heat reduction, and rapid smoke reduction. F-500 is not a foam; it currently is UL-listed as a wetting agent because its other suppression mechanisms fall outside of the current standards. In 1999, the National Fire Protection Assn (NFPA) formed a committee to develop new technical specifications and protocols for F-500.

In addition to its effectiveness in fire suppression, F-500 is environmentally safe and 100% biodegradable. There are no special permits required for the purchase, transportation, or handling of F-500. Typically after a fire incident, the standing water and F-500 are allowed to simply evaporate.

Remove stagnant coal

Even better than suppressing a fire is preventing one, and the first prevention measure for a silo or bunker fire is to eliminate stagnant coal.

Most silos and bunkers have a "funnel-flow" pattern, which is created when the walls of the hopper section at the bottom of the silo are too shallow or rough for the coal to easily slide along. As a result, the coal flows preferentially through a funnel-shaped channel located directly above the outlet while material outside this flow channel is stagnant.

The design results in a "first-in, last-out" flow pattern, leaving stagnant coal that's prone to oxidation and subsequent spontaneous combustion. Funnel-flow, or "rat holing" as it is commonly called, also reduces the usable capacity of the silo.

A mass-flow design, in contrast, puts all of the coal in motion when any amount is being withdrawn. Oxidation and spontaneous combustion of the coal is thereby

PRB Coal Users Group steps up to the plate

Numerous silo and bunker explosions have occurred at US coal-fired plants over the past few years, injuring powerplant personnel and causing millions of dollars in damage per incident to the building structures and conveyor systems. That's not even counting the related loss of generation revenue and cost of replacement power.

In response, several concerned professionals stepped forward to establish the PRB Coal Users Group. Objective of the group is not to lobby for increased burning of the low-sulfur fuel, but to promote the safe, efficient, and economic use of Powder River Basin (PRB) coals. Chairman Randy Rahm, director of coal technical services for Western Resources Inc, Topeka, Kan, has actively studied coal fires and explosions since 1988. He notes that PRB coal presents some special safety concerns, but that the basic principles of fire prevention and suppression apply to all coal-fired facilities.

The next meeting of the PRB Coal Users Group will be March 19-22, 2001, in Baltimore, Md, co-located with the *Electric Power 2001 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, visit www.PRBcoals.com, or go to POWER's Web site (www.powermag.com) and click on "Industry Affiliates."

6. Good housekeeping is crucial to preventing coal-dust fires and explosions

minimized because of this "first-in, first-out" flow pattern.

If you have a funnel-flow system, you should draw down the silos and bunkers periodically to remove stagnant coal. The optimum periodicity can be determined by a plant's experience with each type of coal, and the design of the silos or bunkers. Typically Powder River Basin (PRB) coals should not be left in a ratholing silo or bunker for more than 14 days, depending on whether the PRB coal is fresh off a train or reclaimed from a stockpile (see box, p 56).

Other measures that can be taken to prevent silo or bunker fires include eliminating hot coal from the stockpile (Fig 3), and avoiding sparks from welding or cutting. Hot coal from the stockpile, loaded into a silo or bunker, can mix with stagnant coal and quickly cause a fire. The fires started by stockpiled hot coal can be located anywhere in the silos or bunkers but most likely occur along the outside edges.

Sparks from welding or cutting also can fall into the silos and bunkers, or they can fall onto the moving conveyors that feed them.

Tough questions

One of the most frequently asked questions concerning silos and bunkers is: "What do we do with the coal in a silo if the mill trips and will not be back in service for an extended period of time?" The appropriate answer depends on several factors. How long will the mill be down? How long has it been since the silo was emptied? How old is the coal in the silo? Was the coal loaded straight from a train or from the stockpile?

If the mill is going to be down for less than about 10 days, the silo has been emptied in the past two weeks, the coal is directly from a train, and the CO levels are low, then you should establish a CO_2 blanket or purge on the silo. The CO_2 will help keep the silo somewhat inert and slow down the oxidation process. An air-filled rubber plug should be placed in the feed pipe above the feeder to prevent any CO_2 from bleeding off into the mill. During a CO_2 purge, the silo should be monitored daily for CO buildup.

While CO_2 blanketing is a useful tool for short-term lay-ups, it should not be used if there is a possibility that a fire already exists.

If the mill is going to be out of service for more than 10 days, the coal is from the stockpile, or the silo has not been emptied in the past two weeks, then you should *not* perform a CO_2 purge, but instead should empty the silo immediately.

Firefighting procedures

Another important question is: "What do we do if we detect a silo fire?" The correct response depends on such issues as: the type of coal; where the coal came from—from a stockpile or a train; if the fire is in a silo or a bunker; where the fire is located within the silo or bunker; how much coal is present; if the mill is operating under the outlet nearest the fire; if coal is flowing; and the extent of the fire.

For each of these circumstances, you should develop a firefighting procedure, with careful consideration given to the configuration of your plant's coal-storage system, firefighting equipment, and level of personnel training. All procedures should include the following steps:

1. Close the gate above the mill feeder and shut off the mill-feeder purge air.
2. Shut off all equipment in the area above the silo or bunker.
3. Evacuate the area above the silos or bunkers, and barricade the access to that area.
4. Allow access only to trained personnel equipped with proper firefighting gear, including face and hand protection. Personnel injured in the area of these explosions often are severely burned (Fig 4).
5. Locate and determine the extent of the fire using a laser pyrometer or thermal-imaging camera.
6. Wash down the entire area above the silo or bunker, including walls, ceiling, beams, pipes, and light fixtures. The objective is to remove all of the coal dust from the area (see box, p 54).
7. Activate the silo or bunker deluge fire-suppression system, using F-500 at a 3% concentration. This will remove coal dust from the walls and roof beams, and will wet the top of the coal. In lieu of a permanent deluge system, a hand watering line with a fog pattern can be used, although access to the coal dust on the beams may be limited.
8. After the area has been thoroughly wetted and as much coal dust as possible has been removed, insert a firefighting piercing rod (FFPR) through an opening in the top of the silo or bunker, directly onto the top of the fire. The FFPR may have to be angled toward the fire depending on the location of access holes in the top of the silo or bunker.

Note: The typical FFPR was designed and built by Solid Systems Engineering, Boulder, Colo, for the application of water and a fire-suppressant agent to coal fires that must be fought from the top of a silo or bunker, where safe access into the storage area is limited or not available. The FFPR is designed to penetrate the coal pile by means of a sledgehammer, post driver, pneumatic driver, or an electric driver, whichever is available at the plant. Using the FFPR helps minimize the amount of water and F-500 required to safely extinguish the fire.

9. Once the fire is extinguished, continue to monitor the area with the laser pyrometer or thermal-imaging camera for signs of reflash. Also continue monitoring CO levels in the silos or bunkers.
10. Open drain pipe or pipes located just above the mill feeder gate to decant any water prior to opening the gate.

Keep a vigilant eye

Early detection of a silo or bunker fire is essential to extinguishing it quickly and minimizing its damage. Toward this goal, a permanent CO detector should be installed in each silo and several in each bunker, depending on the size of the bunker. Setting the detectors to alarm on an upward trend over a given time period is the most reliable way to achieve early detection. Other indications of a silo/bunker fire include the smell of burning coal and paint discoloration on the walls of the silo or bunker.

If a fire goes undetected long enough, it creates a cavern. When coal moves into the area, it often causes the cavern to collapse. The silo or bunker area then must be washed down using water with F-500, or else the following chain of events can occur.

If the cavern is located near enough to the surface of the coal when the collapse occurs, it can create a primary explosion fueled by the coal dust inside the silo or bunker. The pressure wave from the primary explosion and the flame front will exit the openings in the top of the silo or bunker. This will disperse coal dust in the conveyor area above the silos or bunkers, and create a secondary explosion.

Don't be fooled by the terminology! The "secondary" explosion is far more powerful than the "primary" explosion, and will cause dramatic damage to the building structure above the silos or bunkers (Fig 5). The secondary explosion will continue to propagate until it consumes the fuel in front of it or it is no longer confined.

War stories

Many attempts have been made to extinguish fires in silos and bunkers using a variety of methods. Some were successful and some were not.

CO_2 blanketing is one common method. In one recent case, a powerplant had an inactive silo on fire that was then blanketed with CO_2 for a month. The fire was slowed but not extinguished. Plant personnel then decided to remove the coal from the silo through the feeder. But they did not wash down inside the silo or in the area above the silo before starting to remove the coal. When the gate was opened at the bottom of the silo and coal flow was established, the cavern that had been created by the smoldering fire collapsed, igniting coal dust in the silo and producing a primary explosion. The pressure wave and the flame front exited the silo into the conveyor area blowing the siding off the building's walls and roof. The pressure wave blew a cloud of dust out of the building, which was immediately ignited by the flame front.

Fortunately, no one was injured in this explosion but the damage estimate was near $1-million.

Another attempt to extinguish a silo fire used dry ice. Several years ago a plant brought in 1000 lb of dry ice to drop through the top of the silo onto burning coal. The first block they dropped only served to disturb the fire, causing a fireball to exit the top of the silo into the building above. Needless to say, this prompted a hasty retreat of personnel. Luckily, there were no injuries, nor were any nearby structures damaged.

Foam is another method used to extinguish a silo or bunker fire. Foam seals off the top of the coal, allowing CO to displace oxygen, which effectively smothers the fire. Only problem with this method is the long time you must wait for the fire to be smothered. How long can the plant staff wait? How many days can you have a mill or several mills out of service?

Water alone is the most common extinguishing agent for a silo or bunker fire. There are many stories concerning the use of water alone, but one that stands out involved a silo fire approximately 10 ft from the top, in a full silo. Volumes of water had been applied until the standing water on top of the coal was a foot deep. But the surface tension of the water and the heat from the fire prevented the water from penetrating the coal pile.

At this point, gases began bubbling out of the water. The gases created under these conditions are hydrogen sulfide (H_2S) and CO, which become explosive at high enough concentrations. An employee who worked at the local fire department remembered seeing a new firefighting agent at the city station. He sped to the station, brought back 5 gal of the new agent, and poured it into the standing water.

Almost immediately, the water disappeared into the coal pile, and the fire was out. That new firefighting agent was what is now marketed as F-500.

Burn safely

With better information and training, future catastrophic coal fires and explosions in the utility industry can be avoided. Fire prevention, which should be the primary focus of all powerplants, requires diligent housekeeping and thorough planning (Fig 6). Recommended operating procedures should be well thought out and documented. Make sure your plant has satisfactory safety equipment and deluge systems installed. It may be prudent to bring in a qualified specialist to evaluate your facility and help develop a comprehensive fire plan.

Most plants do not have the personnel or firefighting equipment to battle fires beyond the incipient stage, so you need to establish contacts that you can call upon if a serious fire breaks out. Know in advance which firefighting agency you will call and ensure that they have all of the information necessary to respond effectively.

Edited by Robert Swanekamp, PE

References

1. M Greiner, Hazard Control Technologies Inc (Fayetteville, Ga, www.hct-world.com), Product Literature on F-500, and "Standard Operating Guidelines Manual, SOG#12"
2. J W Carson, Jenike & Johanson Inc (Denver, Colo, www.jenike.com), "Preventing and Correcting Flow Problems in Bins, Hoppers and Feeders"
3. W Bartkenecht, Springer-Verlag (New York, NY), "Explosions: Course Prevention Protection"
4. D Grandaw, Fenwal Safety Systems (Denver, Colo, www.fenwalsafety.com), "Explosion Protection Seminar Manual"
5. Solid Systems Engineering Co (www.solid-systems.com)
6. Air Cure Inc (Minneapolis, Minn, www.air-cure.com)
7. Fike Corp (Blue Springs, Mo, www.fike.com)