



Derek Stuart, AMETEK Land, USA, illustrates early detection techniques of spontaneous combustion in coal storage and transportation and highlights their importance for plant safety.

BEAT THE HEAT

Between the time a piece of coal is dug out of the ground and is burned in a power plant boiler, it has been through many stages of transportation and storage. One of the advantages of coal as a fuel for power generation is the ability to store substantial quantities on site. This provides a strategic buffer of at least one month's fuel supply, which can be valuable if there is a short- or long-term disruption in the supply chain. Stockpiles also allow producers and consumers to average out seasonal variations in electricity demand.

Transportation of coal from the mine to the plant includes many handling and storage steps. Typically, the

coal is loaded onto a train, unloaded onto a storage pile, coarsely crushed, moved to a day silo and finally pulverised before being transported to the boiler. At each stage, it is important to ensure that the coal is in good condition and can be moved safely to the next.

Oxidation is a critically important problem. When coal is exposed to the air, the volatile components combine with oxygen in an exothermic reaction, leading to spontaneous heating. The Arrhenius equation tells us that the rate of oxidation approximately doubles with every 10°C increase in temperature, therefore a runaway condition can occur in which the coal self-ignites in a process of spontaneous combustion.

In addition to the obvious safety concerns, spontaneous heating and combustion can result in the loss of the purchased coal, which is then no longer available for use in the boiler. Lower rank coals are more susceptible to oxidation than hard coals. Paul Baruya of the IEA Clean Coal Centre has reported that sub-bituminous coals can lose as much as 1.5% of its mass between the mine and the power plant, and Brazilian coal stored for 10 months may lose over 5% of its heating value.¹

Monitoring techniques

There are several techniques for monitoring the effects of spontaneous heating and giving early warning that a dangerous condition may occur. Those techniques mainly work by detecting one of the tell-tale signs of oxidation – either heat buildup or the emission of carbon monoxide (CO) gas. Choosing the most-appropriate monitoring technique depends on both the measurement location and the degree of risk. More sophisticated, and therefore more expensive, monitors are appropriate where low-rank coals pose an increased likelihood of spontaneous combustion.

Large amounts of CO are produced by the inefficient oxidation associated with spontaneous combustion. Ambient air contains a very low concentration of CO – usually well below 10 ppm – so a significantly higher concentration provides a fast and highly accurate indication that unwanted oxidation is occurring. The technique can only be used in enclosed spaces, because the wind will quickly disperse any gas emissions before a measurable concentration can accumulate. That makes carbon monoxide detection ideal for use in silos and storage domes. The sample point should be located near the top of the silo so it can measure the gas in the headspace above the coal. In most cases, a single sample point is sufficient because natural convection ensures that the gases in the headspace are well mixed. Very large or highly asymmetric storage volumes may require additional sample points to ensure adequate coverage.

It is important to verify correct operation of the sensor, otherwise a negative indication can give a false sense of security. For example, a sensor can become plugged with coal dust so that it is no longer exposed to the silo atmosphere. Electrochemical sensors are compact and sensitive, but they give zero output when they fail. That means a faulty sensor will indicate a low CO concentration. In-situ sensors are easy to install, but a blockage is difficult to detect and calibration checks are usually performed manually by a technician with a bottle of calibration gas. Extractive analysers require additional hardware for installation, as the sensor is mounted remotely from the sample point. However, the analysers can detect a blocked sample probe by sensing a reduction in sample flow, and are generally equipped with an automatic calibration mechanism.

Sound the alarm

Choosing an appropriate alarm level for a CO sensor is also important. A low alarm threshold gives the earliest warning of a problem, but it can result in an excessive number of nuisance alarms, which may indicate an unusual condition but may not cause any problems. An excessively high threshold can allow spontaneous heating to progress to the point of being hazardous. The exact value is specific to the fuel type and the storage location, but, in many cases, a value between 100 – 200 ppm works well. An alternative to a level alarm is a rate-of-change alarm. This type of alarm ignores the background level of CO, but responds to the rapid increase that is associated with the early stage of spontaneous combustion.

Temperature sensors are another option for monitoring and preventing spontaneous combustion. Temperature measurements give a direct indication that spontaneous heating is taking place. Because of the time taken for heat to build up, a temperature sensor gives a slower indication of a problem compared to a CO monitor, but it can be used in an open area, such as a coal pile, where ambient air movements disperse the carbon monoxide before a

measurable concentration can accumulate.

Temperature mapping

Direct temperature measurements can be made using a thermocouple inserted into the coal pile. Thermocouples can be up to three metres long, so they can measure the temperature deep within the pile. That may be valuable because coal is a good insulator and buried hotspots are not always evident at the surface. However, there are several significant drawbacks to thermocouple measurements. They measure temperature at a single point, so a large array is needed if good coverage is a requirement. Direct measurements are not practical where the coal is moving, such as on a conveyor.

Infrared (IR) thermometry is a non-contact technique that allows for remote measurement, and imaging techniques are available, which give a 2D map of the coal's temperature. It is important to note that IR temperature measurements can only determine the surface temperature of the coal, so they may miss a buried hot spot. However, the heat generated by the oxidising coal will eventually warm the surrounding material, and the hot CO given off can transfer heat to the surface through convection. Fierro et al noted that infrared thermography has been shown to be very efficient at detecting hot spots in coal piles, and that losses calculated using the technique correlate well with those measured using thermocouple probes.²

An inexpensive portable thermal imager can be used to survey the surface of the coal pile and give an instantaneous map of the temperature. This is an effective technique, but it relies on the skill of the observer. Frequent measurements are expensive because of the amount of time required to take them. A permanently mounted thermal imager allows 24/7 coverage.

Sophisticated image-processing software can detect elevated temperatures on the surface of the coal pile and can reject false alarms caused by moving vehicles and other spurious signals. Improved spatial resolution can be achieved by using a thermal

imager with a narrow field of view, mounted on a pan-and-tilt head. This allows the imager to repeatedly 'patrol' the storage pile and detect any hot spots.

Depending on the shape and size of the pile, multiple imagers may be needed to give adequate coverage. In most cases, the outputs from all the imagers can be combined in a single image processor that displays the results, generates alarms and archives the data for future reference.

Variations in imaging technology

A variation on thermal imaging can be used to detect hot spots on moving objects, such as conveyor belts. Line-scanning uses a single infrared detector and a rotating mirror that repeatedly scans across the moving object, perpendicular to its direction of travel. The combination of the scanning mirror and the linear movement of the conveyor allows the signal processor to build up a 2D map of its temperature. A typical instrument can resolve 1000 points in each scan, with as many as 100 scans/sec. giving very high spatial and temporal resolution. For hotspot detection, the large amount of data produced can be simplified to provide a single value – the maximum temperature within the field of view.

Line-scanning has some advantages over conventional thermal imaging. It has only a single infrared sensor, so the consistency of temperature measurement is better than an image sensor that may have over 100 000 separate pixels, each with a slightly different responsivity. It is important

to remember that a line-scanner, like any other thermal imager, cannot see through the coal and is limited to measuring the surface temperature. Line-scanners can also be used to detect hot spots in railcars by measuring the temperature of the car itself, or in the stream of coal as it is being unloaded from the bottom of the car.

Conclusion

Regardless of the specific measurement technique involved, early indications of spontaneous heating and spontaneous combustion are important to plant safety. These early indicators give the operator time to assess the scale of the problem and to decide on the appropriate remedial action. Appropriate measures may include moving the fuel rapidly to the boiler, so that it can be burned before the spontaneous heating goes too far, or applying fire suppressants, such as foam or inert gases. Early detection prevents loss of fuel, avoids damage to plant and equipment and, most importantly, reduces the safety risk to personnel. ^{WC}

References

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