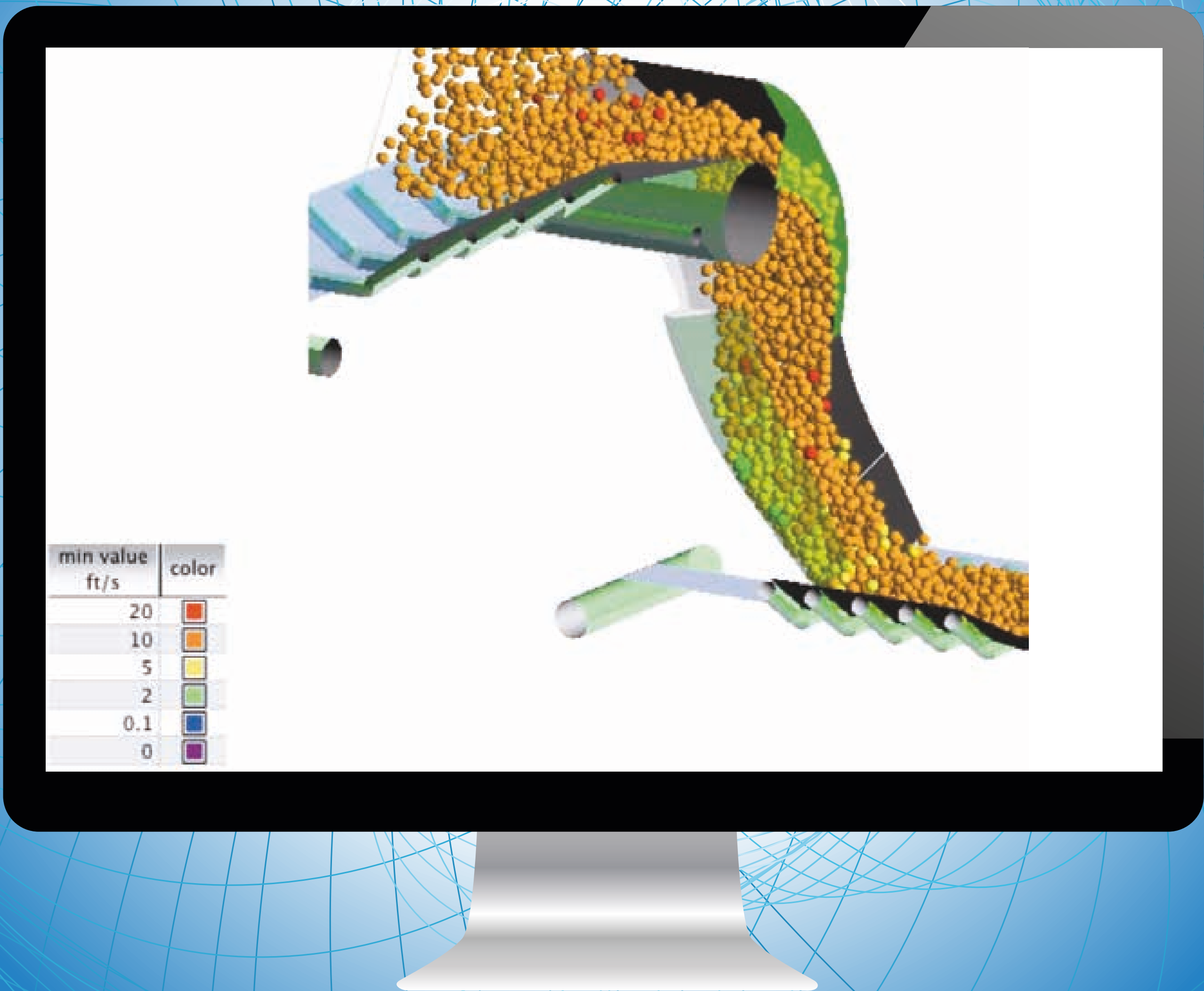
# DESIGN OF THE TIMES

Jayant Khambekar and Tracy Holmes, Jenike & Johanson, US, explain the importance of correctly designed silos, feeders, chutes and coal stockyard gravity reclaim systems.




Whether it is a coal mining facility, coal preparation plant, power plant or a shipping terminal, a coal stockyard is a busy place where several material handling operations occur. Coal stockpiles, reclaim hoppers, bunkers, silos, crusher bins and feeders are typically used for coal handling/storage to provide a controlled feed of coal for various processes. Belt conveyors and transfer chutes are used to convey coal from one location to another. For an operation to be profitable, the entire coal handling system must be reliable. However, the handling system components do not always perform as expected and handling problems related to material flow do occur. These problems can cause flow stoppages, limited live storage capacity and erratic flow, as well as plugged feeders and transfer points. Such issues can result in lost time, lost production, excessive maintenance, safety issues and even

Figure 1. Flow stoppage due to arching over a hopper outlet.

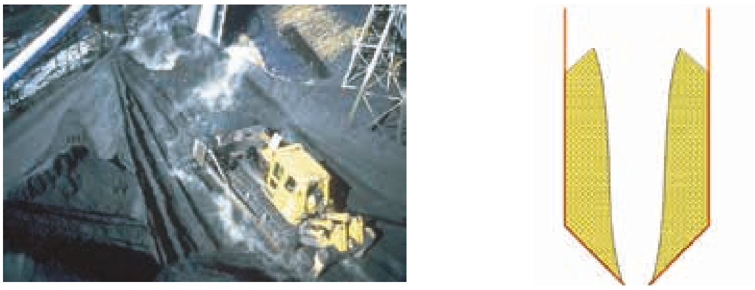


Figure 2. Limited live storage capacity due to formation of a rathole.

equipment failure. This paper discusses coal handling challenges and explores options for alleviating flow problems. While the discussion is focused on coal handling at a power plant, it also applies to coal handling at mines, coal preparation plants and shipping terminals.

## Material flow issues

In a typical coal-fired power plant, coal is unloaded from either railcars or barges to a stockyard where it is stored in stockpiles. Material can be reclaimed from the stockpile using an automatic reclaimer or a gravity-reclaim arrangement consisting of reclaim tunnel hoppers and feeders. It is then conveyed to a crusher house for sizing and transferred to fuel silos/bunkers, which are typically discharged using belt feeders.

In a pulverised coal boiler system, coal is then transferred to a mill via a mill-feed chute, after which it is fed into the boiler. If it is a fluidised bed boiler, coal is transferred directly to boiler-feed chutes from the bunkers. Thus, coal is handled through various processes and equipment.

When material handling systems are not designed properly, flow problems will occur. The most common flow problem experienced when handling coal is flow stoppage. This is a no-flow condition that can result either from arching, also known as bridging, or ratholing.

Arching occurs when an obstruction, in the shape of an arch, forms over the silo/bunker/hopper outlet as a result of the material's cohesive strength (Figure 1).

Ratholing occurs when a flow channel located above the silo/bunker/hopper outlet empties out and the coal outside the channel has sufficient cohesive strength to remain stable instead of falling into it. Once the flow channel has emptied, no further material discharge will occur. In addition to causing this no-flow condition, ratholes significantly reduce the live capacity of a bunker, silo or stockpile. While there may be a large amount of material present, any material that remains stagnant is essentially a dead volume. As a result, the process or equipment may require frequent filling to keep up with the discharge rate. Figure 2 shows rathole formation in a coal stockpile and its effect on live capacity.

When flow obstructions switch between arches and ratholes, erratic flow results. In a typical erratic flow situation, failure of an arch that has formed over a hopper outlet may be induced by an external force, such as vibration, which causes material flow to resume and continue until the flow channel above the outlet empties out and remains stable. If this rathole can be collapsed by a similar external force, it is likely that the falling material will become sufficiently compacted in the hopper outlet area to again form an arch and start the cycle anew. Thus, in an erratic flow situation, material discharges intermittently from the hopper outlet.

Another problem, associated with no-flow conditions, is plant personnel using unsafe procedures to restart flow. Further, when arches and ratholes collapse, sudden dynamic forces act on surrounding equipment. These forces can result in structural damage to silo walls, floors and feeders.

In addition to the cost of these flow stoppages, additional danger exists when handling coals with spontaneous combustion tendency (for example, coal from the Powder River Basin [PRB]) in a system that allows material to remain stagnant. For example, if flow takes place through a channel within a silo, the material outside of this channel may remain stagnant for a long time – depending on how often the silo is completely emptied – and could catch fire. The same problem can occur within gravity-reclaim stockpiles, particularly if there is a significant amount of material in the dead volume.

The development of eccentric flow channels within a silo, particularly due to multiple or offset outlets, can result in non-uniform loading along the outer walls of the silo. This situation could cause wrinkling or buckling of the silo.

Whenever material is transferred from one point to another, it is understood that conveying systems and transfer chutes will be used. Unfortunately, transfer chutes are often designed at the end of the development phase and are therefore made to fit an already fixed layout. If insufficient headroom is allowed for the chutes, then chutes will perform poorly and flow will be disrupted. When a material stream, discharged from a belt conveyor, impacts a chute surface, its velocity decreases. The larger the impact angle, the bigger is the change in velocity. Sliding friction between the stream and the chute surface can decrease its velocity even further, possibly causing it

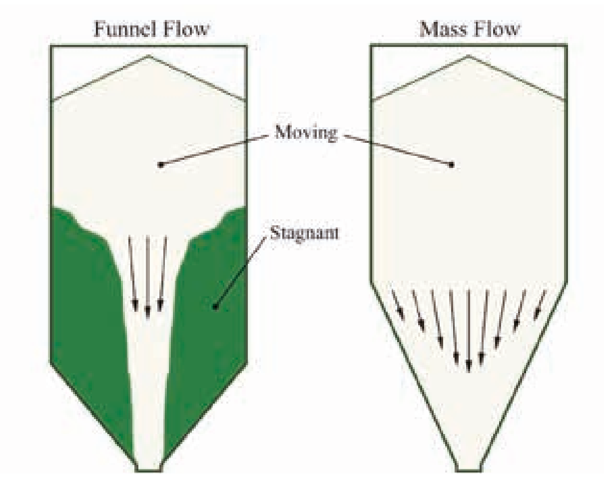



Figure 3. Primary flow patterns in a silo/hopper.

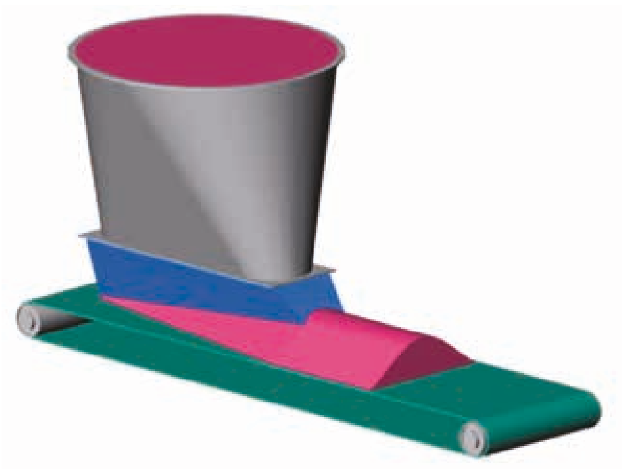


Figure 4. Mass flow belt feeder interface.

to come to a halt on the chute surface, creating a plugging condition. Poor chute design or performance can also result in material spillage.

## Material flow patterns in silos and bunkers

Flow problems and their solutions can be best appreciated by first understanding how bulk material flows. Because bulk materials are discharged by gravity from a storage area, such as a hopper or a silo, two types of flow patterns can develop: funnel flow and mass flow.

In funnel flow patterns, only some of the material is in motion during discharge, while the remaining part is stationary (Figure 3). This type of flow occurs when the hopper outlet is not fully active or when the hopper is not sufficiently steep and smooth enough to ensure flow along the walls. Flow instead occurs through a channel that forms within the stagnant material. Shallow valleys formed in a hopper are a hindrance to flow and can also cause funnel-flow patterns.

Many flow problems are associated with funnel-flow discharge. Funnel flow is suitable only for coarse, free-flowing, non-degrading bulk materials where segregation is not important. Specifically, funnel-flow discharge is prone to ratholing and exacerbates arching tendencies. Coal that remains stagnant in the silo, as a result of funnel-flow conditions, has an increased risk of spontaneous combustion.

The other primary flow pattern that can develop is known as mass flow. This is where all of the stored material is in motion whenever any is discharged. Mass flow occurs when the hopper is sufficiently steep and smooth to ensure flow along the hopper walls. In mass flow, there is no stagnant material during discharge. Thus, many of the problems for silos/hoppers can be eliminated by selecting mass-flow design.

## Measuring flow properties

If a handling system is not designed properly, flow problems will occur. So, the question arises: what approach and design criteria should one use to properly design a coal handling system?

For reliable storage and handling of coal, the geometry construction materials for the system's components must be designed to suit the flowability of the coal. Flowability of a bulk solid is determined by conducting flow properties tests. These are bench-scale laboratory tests that characterise flow behaviour of a given bulk material at representative handling conditions. The critical flow properties needed for a reliable system design are the following:

- Cohesive strength of a bulk material determines its ability to flow reliably, without forming a stable arch or rathole. Information obtained from this test is used as a standard method to determine minimum hopper outlet dimensions to prevent cohesive arches and ratholes and often dictates the flow pattern required in the handling system.
- Wall friction between a bulk material and wall surface of equipment is critical in assessing the flow pattern in an existing system or ensuring the selected flow pattern in a new or modified one. Information obtained from this test allows determination of critical (limiting) hopper angles required to achieve mass flow.
- Compressibility or changes in a material's bulk density, as a function of consolidating pressure, is measured and used in calculations of hopper outlet dimensions and mass flow hopper angles. This data is also used to determine capacity and material induced loads for equipment, such as silos and stockpiles, as well as to calculate speeds and loads for feeders and conveyors.
- Chute angle tests are run to determine the minimum (shallowest) angles required to reinitiate flow after an impact with a chute/liner surface has caused the material stream to halt.
- Permeability is a measure of a material's resistance to the flow of gas through it. The data obtained from this test is used to calculate the critical steady state flow rate of a material as a function of the outlet size and the consolidating pressure, above which two-phase (gas/solid) flow problems, such as flooding or limited discharge rate, may occur. It is particularly important when the material contains a significant portion of fines. This information can also be used to determine the ability of a column of material to seal against gas pressure.

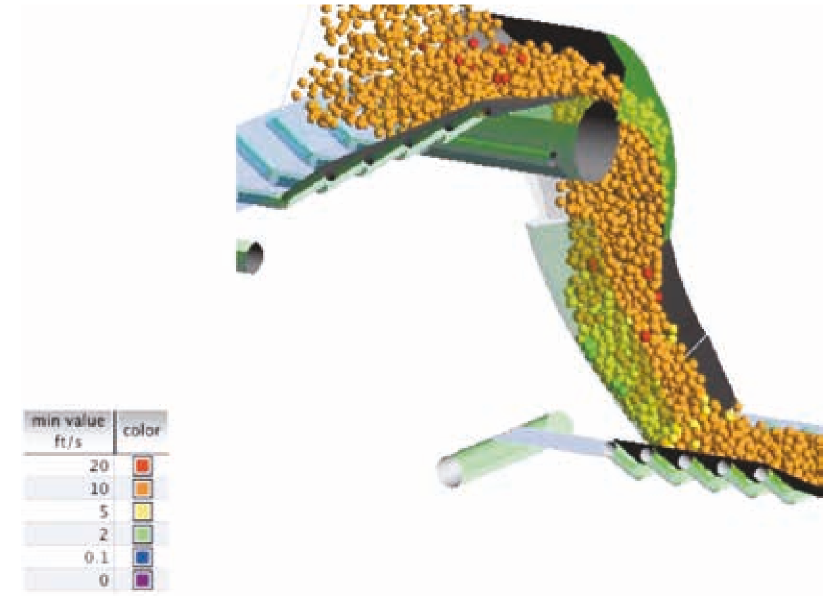



Figure 5. Example of DEM simulation for chute design.

In order to determine the total and live storage capacities of a system, other tests can be performed to measure angle of repose and drawdown angles.

All of these flow properties will be influenced by moisture content, storage time at rest, temperature and fines content, among other factors. Therefore, to design a system that ensures reliable flow, the flowability of a given coal must be determined for the full range of representative conditions.

## Designing a reliable handling system

Properly designed equipment can reliably handle even the most difficult-to-handle coals, whereas poorly designed equipment may not even be able to reliably handle a free-flowing coal. The key to reliable withdrawal of coal from hoppers, silos and bottom reclaim stockpiles is that their design must take the flow properties of the coal into account. This applies to new equipment and modifications to existing equipment.

The outlets of hoppers and silos must be large enough to prevent arches and ratholes and to provide the desired discharge rate. The data required to size the outlet to meet these criteria is provided by the cohesive strength test and the permeability test, respectively. The equipment must discharge the coal in a mass-flow pattern whenever the coal being handled is cohesive or has a tendency to self-heat or spontaneously combust, or when limited live storage capacity is a problem. For mass flow to occur, the hopper walls must be made steep and smooth enough for flow to occur along them. For example, achieving mass flow may require a new liner in an existing application in order to provide a suitably smooth surface. The information required for this type of evaluation is obtained from the wall friction test.

The design of a feeder below a silo/hopper is also critical. If the entire outlet of a hopper is not active, material will be stagnant, even if the hopper was originally designed to achieve mass flow. The feeder must therefore be able to withdraw material from across the entire outlet. To achieve this, the feeder capacity must increase in the direction of flow. As an example, when using a slotted outlet with a belt feeder, this increase in capacity is achieved by using a tapered interface (Figure 4).

Chutes must be designed to be sufficiently steep and smooth to permit sliding and clean-off of the most frictional material that they handle. However, chutes should be no steeper than required to minimise velocities, thereby reducing wear and dust generation. In order to reduce chute wear, free fall heights and changes in the direction of material flow should be minimised.

Discrete element method (DEM) modelling provides an excellent way to understand material stream flow behaviour in a given chute configuration (Figure 5). This knowledge can then be used to optimise the material stream trajectory such that the chute design criteria are satisfied in a modified or new chute configuration.

## Conclusion

Bulk material handling is a key area, yet at the same time, one of the least appreciated. Technology is available for designing hoppers, silos, stockpiles and transfer chutes to eliminate or minimise flow problems in existing facilities and to avoid such problems in new installations. Flow property test data is a vital part of ensuring reliable storage and flow of coals. WC