Optimal plant design

Ben Clark of Derrick Equipment Company (Civil & Underground Construction) looks at some of the factors to be considered when designing slurry separation plants

Derrick model C56 primary shaker with 2mm polyurethane screens

SINCE performance of large-diameter 'slurry shield' tunnelling operations is directly related to the overall cleaning performance of the slurry separation system, it is essential to install an efficient system for removing solids from the drilling fluid.

Solids remaining in the slurry adversely affect slurry excavation processes. Proper and efficient separation of drilled solids from the drilling fluid has many benefits, which include penetration rate (production), reduced drilling fluid costs, reduced water usage, reduced water hauling costs, reduced hauling and disposal costs of contaminated fluid, as well as reduced downstream wear on pumps, plumbing, and other equipment. All this translates into increased production at reduced costs for the contractor.

The drilling fluid – in many cases, a bentonite slurry – creates pressure at the face of the excavation process, suspends drilled solids, and facilitates transportation of solids to the surface, while cooling and lubricating the head of the TBM.

As for cleaning the drilling slurry, contractors generally have three options:

- **Discard and replenish.** This is the oldest – and most expensive – type of solids removal. In the early years of slurry excavation, contractors would completely discard a slurry when it became too heavy or unusable, and totally rebuild their fluid system. In almost every case, this method has proven to be unacceptable and uneconomical.
- **Gravity settling.** Sometimes large earthen pits or tanks are used as settling traps. 'Clean' fluid is skimmed off the top and reused. The settled solids can later be mucked and discarded. This method requires a large area, which on urban tunnelling projects is generally not available.
- **Mechanical separation equipment.** Separation may be performed by vibrating shakers or screens, hydro-cyclones and centrifuges. This is the method principally addressed in this paper.

PLANT DESIGN

Slurry separation plants must be designed to handle the maximum volumetric flows and dry tonnage material delivered from the TBM. They must be able to clean the bentonite slurry enough to maintain acceptable fluid density returned to the TBM without hindering production. Thorough analysis must be performed on the project's geological reports and grain size analysis, maximum flow rates from the TBM, maximum excavation rates, anticipated fluid densities, and other drilling fluid properties. The slurry separation plant provider must consider these issues before designing a plant to meet the end-user requirements. In addition, any spatial constraints or maximum sound-level requirements must be factored into the design process. Density indicates the percentage of solids by volume.

Slurry separation plants utilise multiple processing stages, each designed to remove successively smaller solids. Critical steps within the process provide solids removal capacities equal to the maximum tunnelling rate. During ring-building operations, the re-circulating capability of the plant permits it to respond to challenging and constantly changing soil formations and penetration rate.

Primary separation stage

One method of primary separation is to route excavated slurry from the TBM to a static bar screen with openings ranging from 50 to 10mm. However, these units are fast becoming obsolete, as they are being replaced by more efficient scalping shakers with slow-speed, high-amplitude vibrating motors. Vibrating screening machines permit initial separation of large oversized materials such as cobbles, stones, gravel, sticky consolidated clays, wood fragments, and more. These machines can be single- or double-deck construction, depending on the manufacturer.

Vibratory motion helps de-water the solids and convey oversize material off the discharge end of the shaker onto a conveyor for transport away from the separation plant. In most cases, wear-resistant polyurethane screens with openings ranging from 10mm down to 700µm are typically used at this stage of separation to maximise screen life. Stainless-steel or wedgewire screens are also available, but, in most cases, screen life is lower than for polyurethane screens.

As much of the solids as possible should be removed at this stage to reduce downstream loading and improve overall separation efficiency. Depending on the plant design and/or nature of the excavated solids, the underflow from the primary shaker is either routed to a secondary shaker for finer screening down to 140µm or in some cases fed directly to large-diameter hydro-cyclones for a similar separation of 100-140µm.

Intermediate separation stages

In most cases, multiple stages of separation are employed using desanding hydro-cyclones, followed by desilting cones. Desanding cones process the underflow from the primary or secondary shaker if included in the plant design. A typical desanding hydro-cyclone performs a separation of about 60-80µm at a flow rate of 120m³/hr per cone. Typically, the number of hydro-cyclones is determined by the need to process about 125-150% of the total circulation rate from the TBM.

For optimal separation, abrasion-resistant centrifugal pumps are commonly used to feed the hydro-cyclones at the cone manufacturer's recommended feet of head. Feed slurry directed into the cone inlet at high velocity enters the feed chamber, which creates a spinning action inside the cone similar to a tornado. Centrifugal forces and inertia cause the solids to settle outward against the hydro-cyclone wall in a downward spiralling stream. Solids are concentrated and continuously discharged out at the bottom of the cone, while the increasing centrifugal force near the centre of the cone causes the inner layers of the downward spiralling liquid and finer solids to reverse direction and exit the overflow through the vortex finder.

The desander cone overflow is passed downstream to the next compartment in the base tank of the plant and becomes the feed to the desilter cones. Additional centrifugal pumps are used to feed the desilter cones at the recommended pressure (feet of head). Desilter cones can make a separation as fine as 20µm and process a maximum of 15m³/hr. Again, the recommendation is to provide sufficient desilter cones to process up to 150% of the flow from the TBM.

In most cases, the underflow (recovered solids) from the desander and desilter cones is not ready for handling at this point, as it still contains some free liquid. Consequently, fine High-*g* dewatering screens are used to shake the remaining free liquid from the solids in the cone underflow. The screens form the solids in the underflow into a 'stackable, conveyable' consistency, allowing for easier handling of the recovered solids.

Final separation stage – fine solids recovery

The final stage of separation is to recover the desilter cone overflow solids (material finer than 20um-40um). This recovery is typically achieved by a high-speed decanting centrifuge treating a portion of the desilter overflow. A centrifuge is a high-speed, high *g*-force rotating bowl and scroll assembly capable of separation down to 2 microns. A *g*-force of over 3,000 can be achieved by running the machine at 4,000rpm.

In this process, slurry is channelled through a feed tube into the rotating bowl, where centrifugal force drives the ultra-fine solids outward against the interior wall of the bowl. A rotating conveyor in the centre of the bowl transports the recovered solids toward the solids discharge ports, which discharge into a chute. Liquid is retained in the pool and discharged through the liquid discharge ports.

Dewatered solids discharge from Derrick High-g force linear motion shaker

If desired, polymer injection units can be connected to these centrifuges to achieve a nearly clear effluent; polymer injected into the feed tube will flocculate the reactive ultra-fine solids, forming a large enough mass for the centrifuge to capture. The result is a nearly clear effluent that may be discharged offsite or returned to the system.

Some suppliers offer another option for ultra-fine solids recovery. This method utilises a belt or filter press working in conjunction with a thickening device such as a clarifier. Pre-thickened sludge is fed to a series of plates to squeeze out as much moisture as possible and discharge a dry cake of fine solids. These tend to be maintenance-intensive.

ANCILLARY COMPONENTS AND PLUMBING

The separation plant typically includes a multi-chambered base tank, active TBM working tanks, conveyors, and radial stackers for handling recovered solids. In addition, waste mud tanks are required to eliminate the need for off-site processing.

Bentonite storage silos and mixing systems are needed for preparing fresh drilling fluid, and visual monitoring systems, slurry test labs, along with motor and operator control rooms complete the separation plant.

Carefully designed, sequential plumbing must be provided in the separation plant to ensure proper fluid flow from stage to stage. During non-tunnelling time, the system should be able to re-process fluid through the hydro-cyclones and centrifuges to continuously remove the ultra-fine, hard-to-capture solids.

FINAL CONSIDERATIONS

Slurry separation plants should be designed with health, safety and the environment in mind. Proper walkways, handrails and stairwells should all be included in the scope of supply, along with sufficient lighting and cover from the weather elements, if necessary.

DERRICK SEPARATION EQUIPMENT

Derrick High *g*-force linear motion dewatering shakers can offer an unmatched 7.3*g* of acceleration. High G-forces are achieved through linear motion generated by dual vibratory motors operating at high frequencies. High *g*-forces, combined with fine polyurethane or stainless-steel screens, allow for high capacities, drier solids, and reduced fluid losses than traditional machines.

Derrick, based in Buffalo, New York, offers the industry both unique high-open-area, long-life polyurethane screens and patented stainless-steel Pyramid screen technology as well. This features 3-D or corrugated screen surfaces that offer over 100% more screen surface area than conventional flat screens. This novel design leads to higher shaker capacity, drier solids, and the ability to run finer screens. All are critical components to achieve an efficient slurry separation programme.

Derrick is a family-owned manufacturer of solids control equipment and is one of several slurry separation plant suppliers to the large-diameter tunnelling industry. As well as in oil and gas drilling applications, Derrick equipment is also used for tunnelling, microtunnelling, slurry wall/foundation drilling, horizontal direction drilling, and other underground construction applications.

Derrick DE-7200 decanting centrifuge