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Mining Magazine

Paste picks up the pace

Publishing Date **25 Jan 2012 9:59am GMT** **Author**

Summary

With the use of paste backfill becoming more popular at mining operations, Carly Lovejoy explores the methods used to produce and transport paste

Paste backfill involves the use of mine tailings mixed with appropriate proportions of cement and water, which are transported underground by pipeline to fill mined-out areas.

The use of paste fill originated in the hard-rock mining industry as a practical means of tailings disposal and, in some cases, to aid development. Previously, waste-rock fill (sometimes called cemented rockfill) or hydraulic fill (hydraulic sandfill) were the typical methods of filling underground voids created by mining.

For many years tailings were dewatered and used as hydraulic backfill, which provided a working surface for underground mining operations. These surfaces were not always consistent or sufficiently robust for the associated mining activities, and in some cases they even became sufficiently loose to cause flow failure. Hydraulic fill uses a high volume of water for transport and must also be classified/deslimed (removal of the very fine component) to allow water to drain after placement.

In the 1980s, mining companies began experimenting with better dewatering concepts, and adding cement to the tailings mixture to achieve a better consistency of backfill with some potential for enhanced ground support.

The term 'paste' was coined to differentiate this tailings product from the previous hydraulic backfill. Paste fill was an attractive alternative as it does not usually require classification, nor does it decant significant amounts of water, which would have to be managed underground and pumped back to surface. Paste also offers strength benefits once the cement hydrates, thus providing significant geotechnical advantages.

Waste-rock fill was used fairly often at this time, but with mixed results, and the use of cemented tailings offered many advantages. Rock fill requires considerable expense to quarry and transport under- ground, and usually requires batch mixing and trucking. As paste backfill uses mine tailings, there is essentially no additional cost for the material and operations can be run continuously over several weeks, with only minor monitoring required.

Paste backfill can completely fill a stope without the air gap associated with rock fill, which provides superior ground support. The addition of cement reduces the hydraulic conductivity of the tailings mass and can mitigate concerns related to seepage from the stored tailings.

The placement of tailings underground in the form of paste backfill also reduces the requirements for surface tailings storage facilities (TSF) and the associated mine closure costs. Kevin Connolly of AMEC says: "If paste backfill is utilised to its fullest extent at a given mine, roughly 50% of the tailings can be placed underground."

The low water content of paste backfill can reduce the cost for mine dewatering, pumping and treatment in comparison to other methods. The continuous paste backfill forms a solid block, which can reduce contact with, and contamination of, mine water.

However, every method has its disadvantages. A paste backfill system requires a significant investment of time, money and engineering expertise to get the plant properly designed and operational.

Positive displacement pumps are often required for the lateral transportation of paste (if long horizontal runs exist), which induces associated high pressures in the pipeline system. Significant dewatering facilities are also needed to enable the concentrations required for paste flow to be obtained without loss of fines, and can require more accurate quality control than other fill methods.

Rob Brown of Paterson and Cooke says: "Five to ten years ago, nearly every mining study began with the question, ‘what are the advantages and disadvantages associated with paste backfill?’. Now we are just being asked to design the paste system because the client has either worked at a mine in the past with a paste system or done their own analysis and concluded they want paste fill.

“The advantages can be seen on paper in terms of lower cement consumption, earlier strength gain and improved tailings disposal practices on the surface. However, often it is the intangibles that are harder to quantify, but provide the greatest advantage. For example, few people consider the impact of lower backfill dilution on the overall mining cost. Less backfill drawn into the ore stream creates higher ore throughput and recoveries.

“Very little water bleed is experienced with paste, so the ditches and sumps underground do not handle the same amount of water (and cement slurry) as a hydraulic fill would produce. This translates into lower maintenance costs underground and reduced power consumption for pumping water to surface.”

Hydraulic fill is still advantageous where tailings are unsuitable for the creation of paste and long delivery distances are required. Rock fill remains common where production rates are moderate, waste rock is in abundance and high strength fill is needed.

Mr Connolly of AMEC cautions: “Paste backfill is not a panacea and has been introduced inappropriately at a number of mines. It is an optimal solution for backfill needs at many operations, but sufficient evaluation of options and the full ramifications of having a paste plant as part of the operating mine needs to precede a decision to pursue paste backfill.”

Selecting paste backfill

When assessing the viability of paste backfill, the first step is always a detailed evaluation that compares technical require- ments, economics and environmental/ closure issues for the mine. Paste backfill requires an initial capital investment for the equipment to consistently dewater the tailings and a fixed, underground piping system. These measures increase capital costs and are then weighed against any potential operating savings.

It is also important to consider the proximity of the concentrator to the mine. If the two are separated, the financial and technical challenges of getting the tailings to the site can be a deciding factor.

Paste backfill is often more suitable for longer-term, higher-tonnage operations where the benefits from the capital investment can be fully realised. The paste tailings material must be tested to confirm it can provide the material characteristics required for the mine’s backfill requirements. Issues such as classifying the tailings prior to paste production, the need for reagents and the amount of cement to be added are evaluated at this critical stage.

Not all mine tailings are appropriate for creating a quality paste fill that will flow properly and demonstrate the required strength properties after placement.

Betty Lin, senior engineer for backfill services, mining and mineral processing at Hatch, says: “For example, very fine-grind gold tails and high-sulphide ores can be problematic. Proper pilot plant and strength testing in the study phases is critical.”

When considering upgrading an existing brownfield site to use paste fill, the capability of the existing underground distribution system is another crucial consideration.

Optimising the recipe

Paste is defined as a non-segregating slurry that remains as a homogenous single-stage product during transport and placement. It is a high-density, engineered material. One distinguishing characteristic of paste is its particle size distribution (PSD). Paste contains at least 15-20 wt% of <20micron particles. This amount of fines will allow the mixture to exhibit the required flow properties and retain sufficient water to create a non-segregating fill. At this density, its movement can be classified as similar to that of a non-Newtonian plastic, such as toothpaste.

Typical components in a paste mix (recipe) are: full tailings with the specified PSD; a binder (typically Portland cement); water and a coarse fraction.

The goal for paste formulation is to meet the target properties while maximising the tailings content and minimising the binder content; and to produce a pumpable material that does not segregate when placed. It must neither produce fine material run-off nor require removal of significant quantities of bleed water.

The conditions at each mine site are unique, so the required paste properties will differ. Operations may even use several paste recipes in different fill areas.

The mixture can be optimised in several ways. Although not typically used as paste mix ingredients due to the perceived high added costs, chemical admixtures have the potential benefit of significantly reducing the amount of water to be pumped out of the mix after placement, thus increasing the effectiveness of the process and reducing overall costs.

Mr Brown explains: “We always start by looking at the characteristics of the tailings themselves. The mineralogy, chemistry and PSD will give an early indication as to the suitability of the tailings for the creation of paste.

“The majority of pastes are generated from the total tailings stream. Occasionally, aggregates could be added to manipulate the PSD and create a coarser material. Similarly, the tailings could be classified to remove an excess of fines. The most common way to modify the characteristics is simply to control the water addition and adjust the rheology to suit the mine’s geometry.”

Occasionally, backfill material may have to be imported if the properties of the tailings produced at the mine are unsuitable or if extra material is required to produce a higher-strength paste.

Tailings have become finer in recent years as ore recoveries improve and mineral processing becomes more thorough. The fineness of the tailings affects the water demand of the paste mix. Water demand increases with the fineness of the tailings; therefore, in some cases, to reduce water demand and improve the rheology of the mix, tailings are partially replaced with sand (preferably from a local source) to supply material coarser than the tailings.

The chemical composition of the mixing water has to be compatible with the tailings and binder used for the paste mix. The main concerns are the pH of the water (particularly acidic water with a pH below 6.5) and the amount of dissolved salts, particularly chloride and sulphates.

In situations where fresh water supply is scarce, contaminated water or hypersaline solutions can be used in its place, although the potential for toxic materials to leach into the groundwater must be considered and could be a restricting factor.

Saline water has been used in back- filling at mines in Australia and other areas where saline water is prevalent. Certain cements are designed to resist salt attack and, depending on the salinity of the water, these may be required.

Corina Aldea of AMEC adds: “Testing is required before implementing the use of any non-potable/contaminated water supply. Paste backfill typically results in very low water bleed from the cemented paste, which can, in turn, reduce treatment requirements and costs related to mine water management.”

Binder dosage rates required to achieve typical strength requirements range from 2-6% by weight of the paste mix. General use Portland cement is most commonly used. Supplementary cementitious materials (SCM), such as ground- granulated blast furnace slag, fly ash and natural pozzolans, or waste materials such as cement kiln dust, and finely ground industrial and municipal waste glass can be added to the paste as a partial replacement of cement in binary or ternary blends.

Economic and environmental considerations are the primary driver behind the use of non-Portland cement binders. SCM are known to have good engineering performance besides reducing costs. In addition to technical performance, with certain types of mine tailings the selection and use of a specific alternative binder for paste backfill is primarily governed by sustainable material sources and overall cost-effectiveness.

Ms Aldea of AMEC says: “The paste mix ingredients greatly affect its performance during its transportation, delivery and strength development. Mix designs must be formulated for both placement (rheological properties) and in-situ performance (strength development).

“They must have good long-term durability to ensure stability in a given mine environment, and to meet the limiting strength and pressures that will be developed in the fill. This can be done by choosing the optimal mixes for each type of tailings, as well as by taking into account the cost of the backfilling operations.”

System design

When designing a paste backfill operation (including plant and distribution system), a number of factors should be considered:

• **Tailings characteristics** – PSD; particle morphology, such as particle structure and shape; chemical composition, etc;

• **Rheological properties of the paste** – this will determine its flowability;

• **Depth of the mine –** this affects the pressure rating of the piping system;

• **Location of the paste plant** – this should be optimised to minimise pumping distances and high pressure in pipelines.

Mr Brown explains: "We try to design the process and distribution system to feed the majority of the orebody with the optimal paste recipe. Then we have alternative recipes to feed the fringes of the orebody. The distribution system is designed to run at full capacity to minimise forces on the system and wear. I tend to start at the stope and determine what properties are needed from the backfill (what strength and when), and then design the delivery system and process to meet these needs."

The paste mixture can be optimised using extensive laboratory testing, and it is essential that the designer fully understands the characteristics of the tailings. Mr Connolly from AMEC says: "There are a myriad of problems that can result from a poor mix design, including, in the worst instances, compete lack of ability to place an acceptable backfill. However, it is more common that lesser problems arise such as inadequate support of underground piping, which can cause pipe rupture."

Ms Lin of Hatch agrees that a poorly designed paste mixture can cause excess wear, and the breach of transport pipelines and boreholes. "A recent project completed by the Backfill Services Group at Hatch investigated the wear and restoration of two 1.3km angled paste backfill boreholes. The evaluation of the boreholes found excessive wear to the induction-hardened pipes installed as liners inside the boreholes.

"The wear was so excessive that it breached the system by completely wearing through the pipe liner and surrounding grout. A contributing factor to this was the improper fill mixture and the quantity of coarse material.

"Operating the backfill system at non-full flow conditions also caused the free-falling fill to collide with static fill. This collision, in conjunction with the unsuitable backfill mix, caused an impact zone that eventually breached the pipe. Hatch investigated several pipe-liner techniques and materials, and provided a solution to the problem."

A paste mixture without the proper proportions of coarse material, fines and PSD can also cause water drainage in the mine, which would need to be removed using sumps and dewatering equipment.

Plugging of fill lines or boreholes is also common. This is normally attributed to too much variation in the fill mixture or improper flushing of lines. Ms Lin adds: "Proper design, control and operating procedures are all critical to the successful operation of a paste fill system."

Mr Brown comments: "I have seen many systems that are clearly designed without any consideration given to the material properties. Some mines try to reproduce a design that has worked for them at another operation, but delivery ranges, strength requirements and tailings characteristics can be quite different.

"I would say some of the top problems revolve around the misunderstanding of tailings properties, inadequate dewatering systems and not having a good understanding of what is happening in the underground distribution system.

"Regardless of design, there are also misconceptions about the proper operating and flushing procedures that lead to plugging. Some mines don't realise they shouldn't be flushing the plant wash water/slurry down the paste hole. It is often that transition slurry between paste and clean water that segregates, settles out and plugs the paste line."

Ideally, paste plants should be located directly above or as close as possible to the mined area in order to reduce pipeline pressures and pumping costs. Sloped boreholes are preferable as these can help to reduce air entrainment in the piping system.

Underground piping must be rated for expected potential pressures, and have substantial supports to withstand any system vibrations during start-up and operation. The vertical drop into the mine can be used to supplement or replace the requirement for high-pressure paste pumps.

The design of underground bulkheads for paste backfill must also be adequate to contain paste until the cement has set. Mr Connolly adds: “Excessive cement consumption, in order to meet strength requirements due to lack of initial test work on tailings, is another relatively common problem.”

Bring in the experts

Although some larger mining companies have in-house specialists to consult on their mining projects and provide system design services for mine backfill, most prefer to employ external consultants. The scope of a consultancy’s involvement with a project is dependent upon the services it offers, the nature of the project and its operator.

Many companies offer services for the creation and operation of paste backfill systems. Key players include Hatch, Golder Paste Tech, Paterson and Cooke, AMEC, SNC Lavalin, Wardell-Armstrong and Snowden, among others. Here we look at the services offered by a small selection.

Hatch

Hatch provides a range of services, from scoping level studies to detailed design, including: EPCM services; designing and managing lab tests and flow loops; designing paste mixtures; underground and surface distribution systems; and the detailed design, construction and management of paste plants.

“Hatch has an advantage in that it has leading expertise in the design of concentrators, as well as underground mines,” says Ms Lin. “We can therefore offer clients a complete integrated solution, from mill to mine and backfill.”

Hatch has found that paste fill, with a few exceptions, is the default choice for all new underground mines and, as such, is global in its application. The company is implementing paste backfill systems at a number of gold projects. Gold-mill tailings are typically more finely ground than is optimal for paste fill, so special treatment is required in order to generate a suitable paste. Other challenges include environ- mental risks, and mitigation associated with transporting paste in high-pressure pipelines on the surface and over a river.

“All major mining regions employ paste fill technology,” states Ms Lin. “Paste will stay as a preferable choice of fill for mining operations as recipes are constantly being optimised, equipment is improving, and it helps to reduce the cost and environmental impact of operations.”

AMEC

AMEC offers a range of paste backfill consulting services, from characterisation of tailings through to strength testing, plant design and underground distribution.

AMEC’s Paste & Tailings Group delivers: operations-oriented underground expertise to develop workable systems; rock mechanics know-how to optimise conditions when structural backfill may be required; paste plant process development; tailings and binder evaluation for paste backfill suitability; mix recipe design; material testing and full-scale implement-ation, among other services.

The company has found that the use of paste backfill is particularly prevalent in Canada and the US due to increasingly stringent environmental regulations. AMEC has designed paste backfill plants for a variety of clients, including: Xstrata’s Kidd Creek copper-zinc operation and De Beers’ Snap Lake diamond mine, both in Canada; Sumitomo Metal Mining’s Pogo gold mine in the US; and Aura Minerals’ Aranzazu gold project in Mexico.

A spokesperson for AMEC says: “We are typically carrying out test evaluation work on at least two or three new proposed paste backfill systems each quarter. AMEC specialises in continuous plants (versus batch) with high levels of automation and equipment reliability.

“There is significant interest in paste tailings to extend the environmental benefits of paste backfill technology to surface tailings storage. We have already been involved in a number of projects where there is no surface storage of tailings, and this will likely grow as a viable option for mines to consider in the future.”

Paterson and Cooke

Paterson and Cooke began life as a slurry pipeline engineering company, and expanded to provide a range of specialist engineering and scientific services to the resource industry.

“We design deep-level backfill and mine-fill systems, paste and thickened tailings preparation plants and pipelines, and concentrate slurry pipelines,” explains Mr Brown. “Our services focus on first understanding the material properties by doing all our own test work, and then designing process and delivery systems around the properties we’ve seen first-hand.”

Paterson and Cooke is providing backfill studies for mines in the US, South Korea, Ecuador, Portugal, Canada and Mexico, making repairs in Northern Canada and commissioning a paste plant in Turkey.

Mr Brown adds: “Paste is commonly used in Canada where it has a long history. Mines like to see and feel a new technology before trying it at their own operation. So, as more mines have switched over, others are getting comfortable with it.

“As I mentioned earlier, we find that clients coming to us have usually made up their mind to build a paste plant. Also, as mining engineers move around to other operations, they tend to bring what they know. I have worked with many who have experience at a paste mine and want to quickly bring paste to their next operation.

He concludes: “In the future, I think the underground disposal benefits of paste will become better recognised as surface disposal liabilities continue to rise. Mines will start to maximise placement under- ground and this will lead to the use of several paste mixtures that tailor the cement consumption to the application.”

Thickeners and filters

Thickeners and filters work to dewater tailings and concentrate the solids content of paste. Thickening does this using gravity and flocculants to separate liquids from solids. The latter sink to the bottom of the machine and are removed as underflow, and the water is then removed at the top of the tank as overflow.

Filtration is often used as the second step in the dewatering process, although it can be used alone if the tailings are relatively dry to start with. Slurry is passed over a porous filter medium, which retains solids but allows water to flow away as a filtrate. These solids form a ‘slurry cake’, which can then be removed and mixed with a binder and coarse fraction to create paste.

Sometimes dewatering equipment is not necessary, particularly in arid environments where tailings can be reclaimed from ponds that have drained or dried out. Other operations only require thickeners or filters. The choice depends on the weight percentage of solids in the tailings and the desired weight percentage required for paste, as well as equipment costs. Thickeners nearly always feature in dewatering streams as they are the cheapest initial solid/liquid separation stage.

Steve Slottee of Paste Thick Associates explains: “When designing a paste plant, the first thing that must be determined is the weight percentage of solids and the amount of binder (if used) required for the paste. At this point, the requirement for a filter is determined. If a very ‘thick’ (low slump, high solids concentration) paste is required, a filter will be specified. This would be fed by a thickener. If a ‘thinner’ (high slump, low solids concentration) paste is required, then a deep cone-type paste thickener without a filter will be sufficient for most applications.”

Typically, if the solids concentration required for the backfill process is greater than 75-80%, a filter fed by a thickener is probably required. If a lower concentration is required, a paste thickener without a filter is a possibility. The decision is highly dependent upon the nature of the tailings.

Pumping costs from the thickener to the backfill-preparation station at the mine borehole are also considered. After determining these factors, a thickener (high rate or paste) can be selected.

Chad Loan, global product manager – thickening technology at Outotec, says: “The value of appropriate test work in selecting the optimum design cannot be underestimated. Outotec, for example, conducts dynamic test work to determine the size and design requirements for all thickeners.

“For paste backfill applications we focus on underflow density requirements and predominately high-compression and paste-thickener methodology applies. Our 190mm Semi Pilot test unit, for example, would help determine an appropriate flux rate and resultant underflow density, and we then select the required K factor for the drive mechanism.”

He adds: “It is also vital to work with a supplier who has the experience and know-how to look at the complete picture and is not simply intent on making a quick sale. It is important to consider high availability in downstream equipment (filters, positive-displacement pumps and backfilling pipeline) because if they stop for any reason it is common practice to use the thickener as a buffer tank, and/or use it on recirculation mode.

"Dealing with non-Newtonian (pseudo- plastic material) makes these thickeners work to the limit; hence different problems may occur while recirculating for long periods. An experienced, reputable supplier will be able to review the whole process and avoid such scenarios."

Craig Gilbert, global product manager – thickening at FLSmidth, explains: "It should be understood that, in general, there is a significant difference between the production of 'paste' and a paste backfill system. The production of 'paste' from a thickener relies on residence time, and a specifically designed raking mechanism to allow for dewatering and compression. This releases interstitial water from voids between solid particles.

"Producing paste backfill (requiring lower slumps) from a paste thickener without filtration can be achieved, provided that the material has a suitable PSD. It is possible to produce paste with other equipment (ie filters), but, typically, a high-rate thickener would be used in conjunction with this equipment to produce the material suited to further processing (eg addition of a binder)."

Mr Gilbert adds that in the instance where a filter alone is being applied, the filter cake would usually be diluted to a specific solids concentration to allow for the addition of a binder.

In general, the factors for selecting thickeners for paste backfill would be the same as those for any other thickening application. Among the considerations are: the type of ore; the PSD and whether any upstream processes, such as classification, are required, as pore size distribution and paste porosity have an impact on the ability of the paste to drain water; the chemical composition of the process water and if any additives are required to ensure chemical compatibility of tailings and binders; how the material flocculates; and the required flocculent type and dosage to achieve suitable settling.

The correct underflow density must be determined to allow satisfactory mixing of the binder (if required) into the thickened slurry. If the underflow density results in a high-yield stress, this may dictate the need for a high-density or paste thickener.

In addition, the location of the thickener and spatial constraints must be considered, along with the thickener cycle time required to meet the mining schedule.

If a thickener selection is unsuitable for the paste backfill application (where only a thickener is used), this could result in excessive use of binder and/or exorbitant reagent costs. If the thickener is designed with too long a residence time, it could produce a higher than necessary under- flow density, which would increase binder demand and costs.

Mr Gilbert comments: "If the thickener is inadequately sized for the duty, this could produce a lower than required solids concentration in the underflow, and hence increased flocculent addition as a countermeasure. In this case it would be necessary to try and maintain a balance to ensure over-flocculation does not occur.

"Furthermore, if the paste consistency is not correct it could lead to issues with the strength and cohesion of the paste backfill material, and result in the compressive strength being too low or high. The impact of this could be problems with the flow during transportation, delivery and consolidation, which could result in reduced mining rates due to the increased cycle time for accessing stopes."

Due to the intermittent requirement of most operations for mine paste backfill, a thickener is typically required to operate on a semi-batch basis and it is necessary to store the paste for extended periods.

If the thickener is incorrectly sized, such that it prohibits the formation of a non-segregating paste, this can cause major problems in producing the paste on demand. Additionally, the thickener drive must suit the increased underflow rheology and associated torque requirement, or it will not be able to drive through the paste.

Mr Loan says: "The selection of an unsuitable thickener could result in a reduction in overflow clarity, which will cause poor-quality water to be returned to the plant. It could also increase filter cycle times, and even potentially reduce plant throughput and availability.

"A poorly designed or constructed thickener can ultimately cause unnecessary downtime, reduced production and loss in profits for a mine. So, again, from the outset, the value of appropriate test work and dealing with a reputable, experienced supplier is vital."

Manufacturers

Many manufacturers produce thickeners for use in the production of paste globally. The following looks at the product ranges of three key vendors and designers.

• FLSmidth

FLSmith has three ranges of thickeners suitable for paste backfill operations: Eimco High Capacity Thickeners; Eimco Deep-Cone Paste Thickeners (DCPT)/ Eimco High Density Thickeners (HDT) and E-Cat Ultra-High Rate Thickeners.

Eimco High Capacity machines start with a choice of patented E-Duc, DynaFloc or Dynacharge feed-dilution systems to maximise flocculation efficiency, self- dilution and settling rates. High-rate thickeners are designed to provide roughly 12 times the throughput of conventional machines of a similar size. These units would typically be used for applications that do not require an extremely high solids concentration in the underflow, and would normally be used in conjunction with a filter.

Eimco DCPT/HDTs produce under- flows concentrated towards the upper end or near the limit of pumpability. The deep tank design maximises pulp concentration and produces uniform, non-segregating, paste-consistency underflow slurry.

Mr Gilbert explains: “A DCPT/HDT would be used to produce an underflow with a high solids concentration and yield stress, and therefore could be used to directly produce paste ready for deposition underground. It is also suited to storage of high-yield stress material, which would suit the intermittent demand from underground for backfill.”

The E-Cat Ultra High Rate Thickener has a ‘rakeless’ design, and uses novel technology to accomplish clarification and thickening in a single unit. These models offer low capital costs compared to conventional thickeners, low maintenance costs due to the lack of moving parts, and have a reduced footprint plus low operating costs and flocculent consumption.

The E-Cat is suitable for applications requiring lower solids concentrations than those using the DCPT/HDT, and where space constraints dictate a smaller footprint.

“Any of these models could be used for abrasive and acidic pastes,” explains Mr Gilbert. “The key to ensuring resistance is the choice of construction materials, coatings, and wear materials for various parts of the tank and mechanism.”

FLSmidth has recently undertaken thickener installations at high-altitude projects where, due to the constraints placed on vacuum filtration and difficulties experienced when filtering at low atmospheric pressure, it was decided to apply a DCPT only to produce the required underflow solids concentration for paste backfill.

Mr Gilbert says: “We view the market for the sales of paste backfill equipment as all territories where underground mining takes place with a need for backfilling. The potential for expansion of the market is significant, and the intention is to expand in all geographic territories globally where FLSmidth operates and where underground mining takes place.”

• PasteThick Associates

PasteThick Associates designs paste thickeners for manufacture by its primary client, WesTech Engineering, although the latter has its own in-house expertise for designing conventional and high-rate thickeners. Combining the designs of the two firms, the following range is available:

• Conventional thickener (no flocculent, slurry underflow);

• High-rate thickener (flocculent, slurry underflow) – used to feed a filter;

• High-density thickener (flocculent, paste underflow) – used to feed a filter or produce paste for backfill without a filter; and

• Deep-cone type thickener (flocculent, paste underflow) – used to feed a filter or produce paste for backfill without a filter.

All of these options can be used for abrasive or acidic paste if the correct construction materials are chosen. For example, abrasive pastes may require the use of rubber linings, while acidic materials may require rubber lining or a grade of acid-resistant steel.

Mr Slottee points out that in a thickener, the most likely wear point will be the underflow piping and associated pumping system. “Proper selection of linings and/or steel grades will allow long run times,” he says. “Acidic pastes will particularly affect these potentially vulnerable areas. In general the same comments apply to filters.”

PasteThick Associates is working on a project that proposes a high-density paste thickener feeding a disc filter. This was selected in lieu of a high-rate thickener, firstly because the rheology of the underflow (high slump, low solids concentration) can be picked up by the disc filter and, secondly, when the mine does not need backfill, the tailings can be discharged as paste at the surface disposal area.

“Paste thickeners are a niche market in mine backfill, to be further developed,” says Mr Slottee. “The WesTech Deep Bed Paste Thickener for high underflow solids concentrations, and the WesTech HiDensity Thickener for high solids-throughput rates with lower underflow solids concentrations are our most popular designs. Hybrid designs incorporating the features of both are being developed.”

• Outotec

For paste-backfill, Outotec suggests its High Compression Thickeners (HCT) or Paste Thickeners (PT), along with the appropriate filters from its Outotec Larox range.

Mr Loan says a deep, compressive bed is needed to obtain the required underflow density for paste applications, so these units have relatively high sidewalls, ranging from 4m for a HCT up to 12m for a PT.

“When the depth of the mud bed inside the thickener is raised, the resulting increased hydrostatic pressure provides the driving force to further dewater the bed. However, the increased depth and density of the bed acts as a barrier to liberation of the escaping liquor.

“A common strategy to overcome this decreased bed permeability is to add pickets to the rake arms. These cut vertical channels into the bed and provide an escape route for the liquor,” he adds.

The high-yield stress material becomes harder to pump, so special arrangements must be made to bring the pumps closer to the underflow-discharge point. Mr Loan says a favoured option is to use a cylindrical underflow boot instead of an underflow cone in such circumstances. In extreme cases, a concentric shear-thinning system must be added to the thickener underflow discharge to mechanically shear underflow material and mix it back into the material inside the thickener.

Feedwells also play a significant part in optimal thickener performance. Outotec’s patented Vane Feedwell includes a dual- zone design, which promotes enhanced mixing, energy dissipation and flocculent adsorption. “The Feedwell has shown such impressive results that it is now the global standard on all Outotec thickeners,” says Mr Loan. “Paste and HCT particularly benefit from optimised Feedwell designs.”

For acidic pastes, Outotec would utilise carbon steel, which is rubber lined, 316 stainless steel or a material such as LDX2101 or SAF2205 to enhance the wear life of thickener components.

“We would work with the client and/or engineering company to design specifically for the application,” adds Mr Loan. For abrasive materials, the high-wear sections of the thickener would be lined with rubber.

Outotec was recently awarded some significant high-density thickening projects. These are for large-diameter paste and high-compression thickeners (43-45m diameter) with high-torque drives (9.6- 14.5 Million Nm) for surface disposal. The company explains that, although these projects are not for paste-backfill applications, this technology is suitable for paste backfill and potentially opens up future opportunities.

Mr Loan adds: “Going forward, Outotec continues to spend significant R&D resources on thickener design and we hope to announce some further important developments from site installations very soon.”

Pumps

The majority of mine-backfill operations use the thickener/filter combination to achieve high solids concentrations and reduce cement consumption. For large, shallow mines, pumping paste over long distances can be a major cost. In these instances, a paste thickener without a filter can be used at the expense of higher cement use.

The key difference between a filter paste and a thickener paste is what is called ‘pumpability’. If a paste thickener is used, the underflow will flow out of a properly designed tank and can be pumped, often with a centrifugal pump.

A backfill paste, which is prepared from a filter cake, will usually require a positive displacement pump. These pumps can be crankshaft-driven diaphragm, hydraulically-driven piston with actuated assisted valves or hydraulically driven piston with transfer tubes. Diaphragm pumps can only pump paste with a limited particle size and at limited pressure, making piston pumps more popular for paste backfill.

The main factors to consider when selecting pumps for paste backfill are:

• **PSD –** for large particles, transfer tube pumps are most suitable;

• **Solids percentage of the paste –** the higher the solids fraction of the slurry, the lower the flowability. This determines the required pumping pressure and has an effect on pump design due to maximal internal slurry velocities inside the pump;

• **Required total pumping pressure –** this depends on the static and frictional pressure;

• **Required flow capacity in m^3/h;**

• **Potential effects of pulsation in the pipeline –** type of pump can determine whether pulsation occurs in the backfill pipeline system. Pressure pulsations are notorious for creating pipe vibrations that can damage the system and create unwanted noise; and

• **Investment costs versus operational costs (APEX vs OPEX).** When the backfill paste is of medium viscosity, two types of pumps are applicable: a crankshaft-driven piston membrane and a hydraulic piston pump. As these types of pumps have different operational and investment cost characteristics, the choice will be based on project specifications, such as duration, hours of pumping per day and electricity rate.

The performance of the backfill system depends on the selection of the correct type and size of pump. In the worst case scenario, poor pump selection may result in a paste-transport system that does not work at all. In general, an improper selection can lead to cavitations, vibration and much higher wear during normal operation.

Charilos Karambalis, product manager for GEHO pumps at Weir Minerals, says: “If a pump selection does not meet the project requirements, the mean time between maintenance (MTBM) intervals will be lower, decreasing the availability of the system. This can have an impact on the backfill schedule and, subsequently, on mining schedule and production output.”

The pump is an integrated part of the backfill system, and Mr Karambalis says that Weir always approaches the selection of a pump in the context of the complete system design. Many basic factors, such as paste flow velocity in combination with pipeline diameter and length, will influence the design of the system and therefore of the paste pump.

Gravitational backfill is also widely used around the globe, but it is highly dependant on the location of the mine and the paste plant. Often a pump is required when the underground backfilling area has progressed, and the distance from the plant has become too great for a gravitational feed system.

Another possible reason for using a pump is when the backfill process requires a very thick paste (with a high solids percentage) and the flowability of the slurry is unsuitable for gravitational backfill.

Manufacturers

Here we look at the product ranges of three key global pump manufacturers.

Weir Minerals

Weir recommends its GEHO range of positive-displacement pumps for mine paste-backfill applications. The range includes crankshaft-driven diaphragm pumps, which are suitable for medium-viscosity backfill slurries with a solids percentage up to 70%. Because of the type of crankshaft used, these pumps are extremely efficient and offer low operational costs.

Type DHC/DHT hydraulically-driven piston pumps are also available, which can handle extremely viscous slurries with a solids percentage up to 90%. The DHC is designed for smooth, high-density slurries and can offer pulsation-free discharge flow. The DHT is a ‘valves-less’ paste pump that can handle large particles up to 100mm diameter (depending on the past properties and PSD) by means of a transfer tube.

The range also includes hydraulically-driven diaphragm pumps with APEXS, Weir’s Annular Pressure EXchange System. This is a positive-displacement pump consisting of two or three sloping tubes and a hydraulic power pack. The slurry is forced out of a long, cylindrical elastomer tube contained in steel-pipe pressure housing. The cylinders alternately evacuate the slurry, and are timed to provide a continuous, pulsation-free flow.

Advantages include the pump’s ability to handle acid and aggressive slurries, as the elastomer tube (or hose diaphragm) physically separates the slurry from the larger part of the pump. The APEXS runs at an ultra-low rate of approximately 4/min strokes, which results in low wear and high reliability. The pump’s modular design allows for easy transport and quick assembly once underground.

All of the pumps are available with special construction materials such as wear-resistant steel or ceramic layers to meet specific application requirements.

Mr Karamabalis comments: “The lifetime of pump wear parts is dependent on the properties of the paste. We have observed wear part lifetimes of 500h for highly abrasive pastes and up to 5,000h with less severe pastes.”

Weir recently supplied a pump for a Russian iron-ore mining project. The paste contained large particles up to 40mm diameter. Mr Karambalis explains: “We selected a GEHO DHT transfer tube-type hydraulic piston pump, which is the only design that can handle this rough backfill material. The pump has recently been shipped and will be commissioned in March quarter 2012.

“In the past year we have received an increasing number of enquiries for paste applications, including those with large particles and high flows. It is obvious that in the field of mine backfill there is an increasing trend towards high-density paste pumping.”

Putzmeister

For paste handling, Putzmeister produces double-piston pumps that can handle maximum grain sizes up to 63mm, with outputs up to 400m³/h and pressures to 15MPa. These are suitable for use with slurries, high and low-slump pastes (with or without coarse grain sizes) and, if necessary, they can pump filter cake.

Peter Peschken, application manager for mining at Putzmeister Solid Pumps, says: “Our piston pumps are made for handling abrasive materials. According to the paste design, Putzmeister can deliver different build materials for wear parts to best fit customer’s needs. Our piston pumps are suitable for paste with pH values of 4-14. If the pH value is below 4, we can custom-design a pump.”

Putzmeister is about to start work at Barrick Gold’s Porgera gold project in Papua New Guniea and the Goldstrike project in the US. At both sites, Putzmeister will commission HSP 25.100 HP double-piston pumps. The delivery cylinders are 360mm diameter and 2.5m long. Mr Peschken says that due to the size of the pumps, the number of switchovers is reduced and the lifetime of the wear parts is increased.

The company’s HSP 2180 HP seat valve pumps are also used to pump fine-grained ‘salt-concrete’ at a German Kali & Salz potash mine to stabilise it.

At Feng Feng coal mine in China, two KOS 25.100 HP double-piston pumps with S-transfer tubes are used to pump paste underground, where its is used to prevent subsidence. It contains gravel particles up to 20mm diameter. Each of the pumps can handle 150 m³/h of paste.

Putzmeister counts China, the US and Russia as some of its biggest sales markets, and notes that customers are increasingly asking for bigger pumps with higher outputs and pressures.

ITT

ITT launched its Goulds Pumps XHD (Extra Heavy Duty) lined slurry pump in November 2011. The XHD is suited for use in Hydraulic Institute Service Class III (heavy) applications, including thickener underflow, tailings disposal and slurry transfer, and Class IV (very heavy) applications such as primary grinding circuits, heavy media, thickener underflow and tailings disposal.

The XHD has a capacity of 2,950m^3/h, with up to 85m of discharge pressure. The product range includes six models with 80-300mm discharge and a choice of four power frames.

The XHD has a double-wall construction with a large-diameter, closed impeller, which extends wear life by enabling lower RPM operation. The use of computational fluid dynamics has allowed the pump to be hydraulically optimised for higher efficiency, longer wear and lower power consumption.

Customers can choose from a selection of HC600 replaceable chrome-iron liners to extend pump wear life. The compact frame contributes to accurate alignment and provides rigid, vibration-free support.

ITT expects XHD shipments to start in the March quarter 2012. The company will introduce rubber-lined versions in late 2012, and an expeller option will also be available in mid-2012. In addition, ITT plans to add more pump sizes and higher pressure capabilities to the range in the future.

Four types of mine backfill

Dry Fill

• Consists of surface sand, gravel, open-pit waste rock, underground waste rock and smelter slag

• Generally unclassified, except to remove large boulders

• Transported underground by dropping down a raise from the surface directly into a stope, or to a level where it is hauled to a stope with LHD or trucks

• Suitable for mechanised cut and fill, or methods where structural backfill is not required

Cemented Rockfill

• Consists of waste rock mixed with cement slurry to improve the bond strength between fragments

• Placement involves mixing rock and cement slurry before placing in stopes, or percolating slurry over the rock after it has been placed

• Can be classified or unclassified

• Suitable for longhole open stoping, undercut and fill, and other methods where a structural fill is required

Hydraulic Sandfill

• Consists of classified mill tailings or naturally occurring sand deposits

• Prepared by dewatering the mill-tailings stream to a density of 65-70% solids and then passing it through hydrocyclones to remove slime

• Mixture is hydraulically pumped from the surface through a network of pipes and boreholes to the stope

• Sandfill can be cemented or uncemented

• Cohesion often develops in uncemented sandfill, which increases the shear strength. A vertical face of 3-4m can be maintained under some conditions

• Nearby blast vibrations compact the fill and increase its shear strength

Paste Backfill

- High-density backfill (>70% solids)
- In order to pump at this density, a component of fines is required
- Slump of paste is 18-25cm
- Pumped using piston-type pumps – the same as that used to pump concrete
- Whole mill tailings are used to make paste backfill
- Many mines are moving towards paste backfill as a low cement content is required to gain equivalent strengths when compared to conventional hydraulic fill