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A comparison of two paste plants in India

C Lee *Golder Associates Ltd., Canada*

G Chatterjee *Golder Associates Consulting (India) Pvt Ltd, India*

A Gandhe *Golder Associates Consulting (India) Pvt Ltd, India*

BV Rao *Hindustan Zinc Ltd, India*

A Nirvan *Hindustan Zinc Ltd, India*

DP Ravikumar *Hindustan Zinc Ltd, India*

Abstract

Hindustan Zinc, a subsidiary of Vedanta owns and operates the Sindesar Khurd (SK) mine and the Rampura Agucha (RA) mine both located approximately 250 km away from each other in Rajasthan, India. Both mines are underground zinc mines which are primarily mined using sublevel open stoping (SLOS) and are transitioning from the use of hydraulic fill and cemented rockfill to the use of paste fill. Although the two mines have similar mineralogy, similar tailings particle size and similar strength requirements the two paste plants had surprisingly different recipes, plant layout and equipment selection in order to accommodate substantial differences in tailings rheology, dewatering and strength properties. In addition, the two paste plants have very different distribution systems with one system requiring long horizontal pumping distances and the other having a gravity distribution system. Interestingly, all the challenging characteristics such as poor dewatering performance, low strengths, and longer horizontal distribution system all are associated with the RA mine while the SK mine enjoys better dewatering, higher strengths and a simpler distribution system.

The paper describes the methodology, challenges and opportunities associated with designing and construction of a paste backfill system in India as well as an interesting comparison between two paste plants to illustrate just how sensitive the design of a paste plant is to the tailings properties. It also provides an interesting comparison at the extremes of plant design resulting from excellent tailings properties and favourable orebody geometry versus challenging tailings properties and unfavourable orebody geometry.

1 Introduction

In 2011 Golder Associates were retained to perform the design, construction and commissioning of two paste backfill systems at the SK and RA mines in Rajasthan, India. The two plants are shown in Figures 1 and 2. These two paste systems were to be the first facilities of their type constructed in India. Due to the lack of Indian experience with paste systems and a desire to make sure that the designs would be constructible and operable in the Indian mining environment, Hindustan Zinc Limited (HZL) developed the project with some key differences compared to project development in other parts of the world.

An additional, interesting outcome from the design of the two plants was the substantial difference in plant design and cost despite the fact the two mines had many similarities in mine design and tailings materials. The difference between the two plants illustrates just how sensitive paste plant designs are to the tailings properties, physical geometry of the distribution system and stope sizes.

Golder is frequently asked the question ‘how much does a paste plant cost?’ without having any testing data available and it is sometimes difficult to explain that the variation in plant capital and operating costs can be huge and that these systems are not off the shelf. The difference between the two HZL paste systems shows how important proper testing and process design is before the configuration and cost of the system can be estimated with any degree of confidence.

Figure 1 RA mine plant

Figure 2 SK mine plant

2 Staff preparation and training

In India there is no shortage of skilled and unskilled labour at a very low cost. HZL recognised the importance of ensuring that the operation and maintenance staff were adequate in numbers to perform all the functions in the paste plant; however, they were concerned about the preparation and training of the staff to ensure their readiness when the plant was commissioned.

In most parts of the world operators and supervision staff are hired and trained near the end of the construction period and then there is a period of several months of commissioning and training where the operators learn how to operate the plant under the guidance of the design consultants. This works well in most parts of the world where some of the operators have paste plant experience and there is enough prior industry knowledge so that the experienced personnel can teach the less experienced personnel during the startup phase.

In HZL's case, there was no prior experience with paste backfill in the country and it was not possible to hire experienced operators. In addition HZL was interested in a greater level of preparation so that their staff would begin the operation of the plant with some experience. Finally, HZL wanted to have a preliminary look at how a paste plant system was operated; from planning, organisation and preparation all the way to the actual operation of the plant and integration with mining activities.

To this end HZL asked Golder to provide a training course at an operating mine where 11 of their staff could spend several weeks in an operating paste plant learning the skills that they will need when managing their own paste system. This course was provided and 11 staff spent two weeks at the Kensington Mine in Alaska where they observed and participated in the complete system operation.

While this training effort was not without cost, the ability of HZL staff to observe and participate in the tasks that were applicable to their role in the new plant was highly instructive and gave HZL staff a feel for the work. For example, maintenance personnel were able to participate in the change-out of piston pump poppet valves and seats, change filter bags, see the cleanout requirements for the dust scrubber etc. This also was true for the various tasks and responsibilities performed by the HZL process engineers, operations supervisors, mining engineers and planners that took part in training for their respective fields of specialisation.

3 Modern plant for the Indian environment

Throughout the paste projects and other projects with HZL it was apparent that there was a recognition at senior management level that to improve HZL's operations and maximise the profitability of their assets the latest in modern mining technology should be used where appropriate.

It was recognised by HZL that even though many of their operations relied on inexpensive labour to be profitable, this was not necessarily always going to be true and preparation should be made to address a workforce that could become more expensive in the future. In addition, there was a genuine desire to bring a level of professionalism and quality to mining operations so that performance could be measured and controlled with a high degree of automation and precision. And finally, it was recognised that reducing the number of personnel in an operation and minimising labour intensive tasks would reduce the likelihood of injury.

Notwithstanding the thoughts above, the design of the plant had to be suitable for the Indian environment and it was not intended to adopt a degree of automation or component design without good reason. Some of the highlights of the design for the Indian environment are as follows.

3.1 Selection of materials and equipment

In India the cost of certain types of equipment and materials can be substantially lower than elsewhere in the world.

Reinforced cement concrete (RCC) is widely used whenever possible. Semi-skilled labour for the mixing and placement of concrete as well as the placement of rebar is extremely inexpensive and reinforced concrete can be used at a fraction of the cost of steel in many cases. Readymix concrete from batching plants are used for large volume pouring, whereas for smaller volumes, portable cement–concrete mixing machines are commonly used. As a result of this, many of the elevated floors of the paste plant could be constructed of concrete which is superior in terms of housekeeping. While this seems like a small consideration it is a real advantage since cemented paste build-up on a multi-floor plant with grating can be problematic and reduce the life of instrumentation, valving and electrical components.

When building steel structures, Indian contractors do not necessarily use standard rolled sections and, especially for columns and beams of large sizes, built-up sections made of steel plates or multiple rolled sections or both are fabricated. This allows the freedom to use larger building/bay spans and columns at minimal additional costs. The sizes of Indian-manufactured rolled steel beams are limited and except for smaller columns and floor beams, built-up sections were required at many areas in the plant. The result of the use of built-up steel sections is the ability to minimise the amount of steel in the plant since the built-up sections use steel more efficiently to provide the strength required. The cost of fabrication of these built-up sections would be prohibitively expensive in high labour cost environments; however, in India the use of fabrication labour to save on steel usage is justified by the lower labour cost.

Figure 3 Built-up steel sections

Figure 4 Built-up steel sections

Piping materials also can be shop fabricated rather than factory fabricated and this is true of flanges which are cut from steel plate rather than fabricated of forged steel. While the quality of these shop-made systems is lower than the components from a reputable supplier they can be used in low-pressure applications at considerable savings.

The built up structural sections are shown in Figures 3 and 4. The forged, factory fabricated pipe flange is shown in Figure 5 on the left and the field fabricated flange is shown on the right.

Figure 5 Factory fabricated and field fabricated flanges

There are many equipment manufacturers in India which hold the patents or design rights for various types of typical mining equipment such as centrifugal pumps, valves, vacuum pumps, (Figure 6) dust collectors, etc. These components can be procured at a considerably lower cost than international equipment suppliers can provide. There are some cases where the equipment materials and/or design might be outdated or not to current standards; however, there is opportunity on a case by case basis to take advantage of the lower pricing and convenience of local supply.

Figure 6 Indian-made vacuum pump (PPI Pumps), supplied by FLSmidth

3.2 Selection of a system design

Although HZL was keen to have a paste plant design that uses cutting edge technology and design there was also an acknowledgement that the plant needed to be suitable for the Indian environment. Balancing these two issues was a major consideration during the design of the system. Some of the considerations during the design process are listed in the following sections.

3.2.1 Barricade design

Barricade design is a critical component for the design of backfill in underground mines. The purpose of providing the barricade in the drift near the stope is to plug the opening and prevent the backfilled material from flowing out until the backfill cures and plugs the drawpoint so that subsequent pours can be undertaken. HZL were highly cognisant of the dangers of barricade failure and because of the fact that pastefill is not currently used in any Indian mines, the mine staff wanted to understand the risks and be sure that proper design considerations for a pastefill barricade were being considered.

Golder performed two separate barricade designs, one using shotcrete and one using waste rock. Shotcrete was the preferred method for RA mine staff and they have elected to pursue only shotcrete barricades. While SK mine had some concerns about using muck barricades, they do not have a shotcrete system at the mine and therefore shotcrete barricades were not an option for them.

In the end, SK mine elected to install a timber barricade that they had used before for cemented hydraulic fill (CHF). The timber barricade is filled in multiple lifts to limit the hydraulic head on the barricade.

Figure 7 Timber bulkhead at SK mine

3.2.2 Continuous mixing

One of the primary decisions at the beginning of any paste backfill process design is the selection of a continuous or batch system. This topic has been discussed in many other papers so the pros and cons of the two methods are listed only briefly here.

Continuous mixing has the advantage of being less expensive due to less equipment and a smaller, lower plant layout. Continuous mixing is also a simpler process and is easy to understand and control with a simple programmable logic controller (PLC) program.

Batch mixing is slightly more complex and more expensive. However, batch mixing systems typically have better mixing quality due to multiple stages of mixing and the ability to mix the first stage in a high viscosity state (which allows better mixing of sticky, cohesive filter cake). In addition, batch mixing is more reliable when it comes to ensuring that out of spec paste does not end up underground. Viscosity control and proportioning of recipe ingredients are much more reliable in a batch system than a continuous system and a batch system is controlled so that nothing will be discharged underground unless it is within the required range of viscosity and dosing accuracy. With continuous systems there is frequently a time delay before the slump control and dosing control can recover from a stoppage in flow or other interruption of the process.

Both RA and SK mines will require low slump paste (175 mm) and therefore the poor mixing encountered when mixing cohesive filter cake in a low viscosity medium as is the case with higher slump paste is not expected to be a problem. The distribution systems for both mines are not overly long and precision viscosity control is not expected to be as important compared to longer systems. Finally, the capital cost of the batch system vs. the continuous system was evaluated and determined to be too expensive to warrant the additional degree of control and efficiency of cement usage.

A continuous mixing system was therefore selected for both SK and RA mines.

Figure 8 RA mine continuous mixer

3.2.3 Deep tank and high compression thickening

Both the SK and RA systems are comparatively large systems. This can be viewed as a challenge or as an opportunity to be able to build some economies of scale into the design. One of the ways in which to increase the efficiency of filtration equipment is to feed the filters with higher percentage solids slurry. The filter production rate increases exponentially as the filter feed percentage solids goes up and filters can be extremely efficient if fed with a high density slurry.

In the case of RA mine, the mine has an existing deep tank thickener which is used to dewater the tailings stream prior to discharge at the tailings area. That thickener is able to feed the RA paste plant with a slurry feed percentage solids of 58%.

Similarly at SK mine, a high compression thickener has been included in the paste system design which can feed the filters at a percentage solids of 70%.

3.2.4 Drilling boreholes

Drilling boreholes for the paste system in India proved to be quite difficult since the area is underserved by suitable contractors who have the equipment and experience to drill inclined holes up to 400 m long at dips ranging between 60 and 70°. Previous experience at RA mine with the drilling of long holes caused HZL staff some concern since the accuracy of the holes were poor and they had difficulties surveying the hole adequately in order to drift into the hole breakthrough accurately.

Although an extensive search was performed for drilling contractors that were willing to ship their equipment to India and provide directional drilling for a 300 mm diameter hole none of the large drilling contractors that Golder typically use were interested in the project.

In the end, it was decided to use Bergteamet, a Swedish drilling contractor who supplied a raisebore capable of drilling the surface holes at the angle and depth required. At the time of writing this paper three holes from surface have been drilled at SK mine. The inclination of the two deepest are 55 and 71° with a vertical distance of 261 m, and the shallow borehole is 64° with a vertical distance of 151 m. All boreholes are drilled with a 325 mm diameter bit.

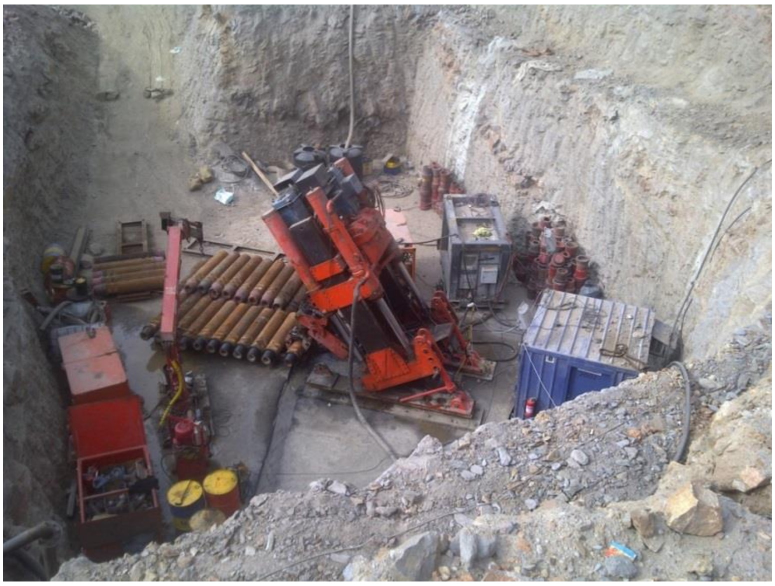

Figure 9 Raisebore drilling surface holes at SK mine

3.3 Selection of a design build contractor

In India, a design build method of project execution is typically preferred. In other parts of the world it is more common for the design of mining infrastructure to be completed by an engineering firm and then the completed design is used for contractors to quote on the construction. This is especially true for projects where the direction that the design will take is unknown due to lack of information regarding material properties, site conditions, etc.

To accommodate HZL's desire for a design build type of project execution, Golder performed the material testing, process design, equipment specification, basic engineering for the plant, and detailed engineering for the underground and produced a specification and request for quotation (RFQ) package that was used to procure design build services from an Indian contractor.

During the design build stage Golder was also tasked with reviewing all of the Indian contractors work and performing the design of 'paste-specific' items that the contractor would not have knowledge of. Golder also provided construction supervision and commissioning/training services for both the paste plants.

This methodology allowed HZL to take advantage of Golder's paste system design knowledge while still using their preferred design build contractual model for the bulk of the project. This method also allowed HZL a greater level of quality assurance since Golder was acting as a check on the contractor's design and construction activities and ensuring that the contractor delivered a quality product.

Finally, this method also ensured that local materials, design codes and methods of installation were efficiently incorporated into the design so that the design was appropriate for construction in India.

Although this method is not appropriate in every part of the world, it has proven to be quite effective in India.

4 Key differences between the two plants

4.1 Tailings properties

Initially, prior to the testwork program it was anticipated that the design of the two plants would be very similar. Both mines were zinc mines with similar production rates and although there was some differences in mineralogy and particle size, those differences were not considered major in the sense that the RA mineralogy looked no worse than the SK mineralogy for the purposes of dewatering, rheology and strengths.

The particle size and mineralogy are summarised as follows.

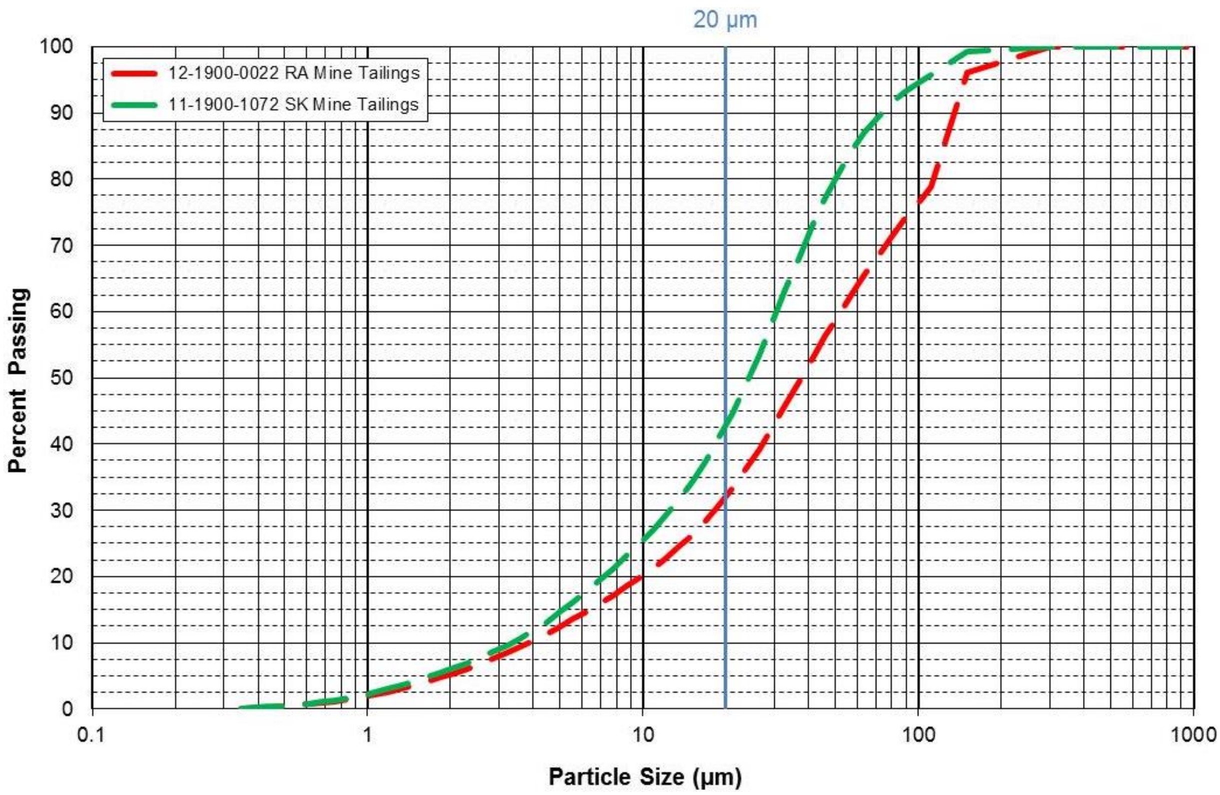

Figure 10 Particle size comparison

The particle size for SK mine can be seen to be slightly finer than RA mine which would indicate that better strengths and dewatering characteristics could be expected for RA mine. However, that was not the case as discussed later in this paper.

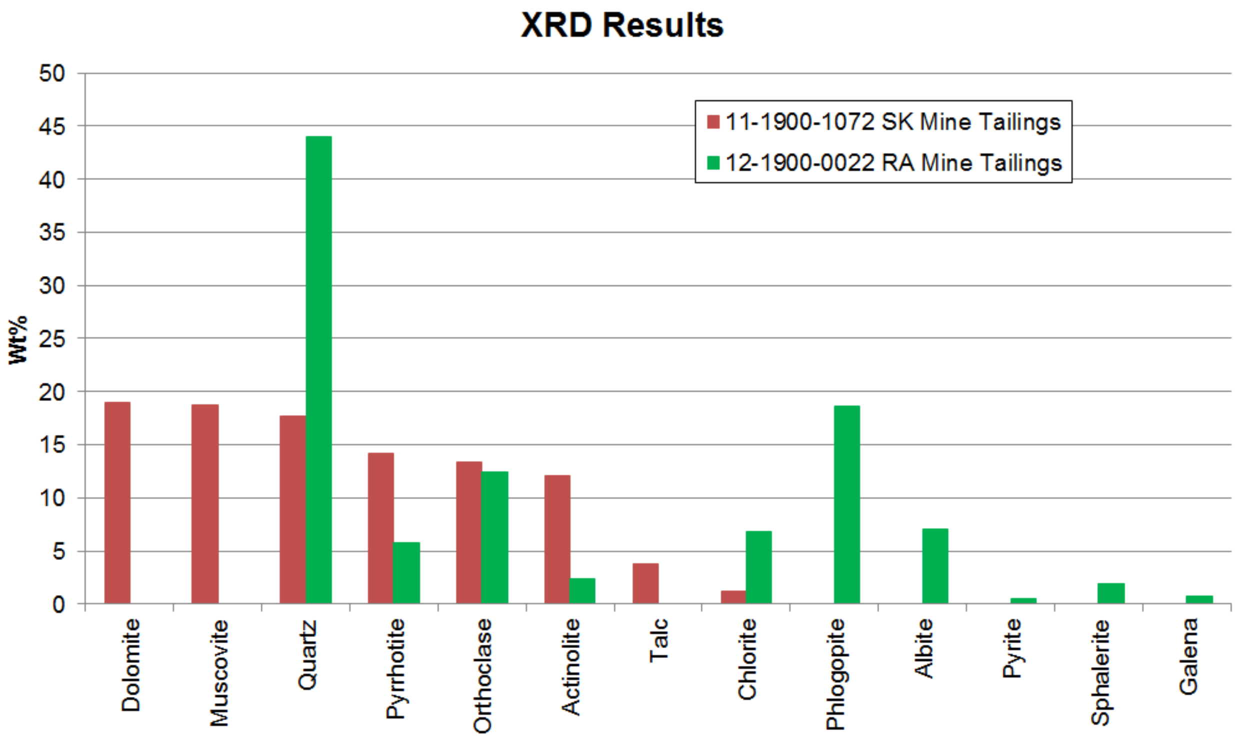

Figure 11 Mineralogy comparison

In actual fact, the behaviour of the two mine tailings were substantially different. The filtration rate for the RA mine tailings was much lower than the SK mine tailings which required more than double the filtration area to achieve the same tonnage. The additional filtration area requires extra filtration equipment, higher power consumption for the additional vacuum pumps, additional piping, electrical and instrumentation and a larger building. The additional cost due to the greater required filtration area resulted in millions of dollars of additional capital.

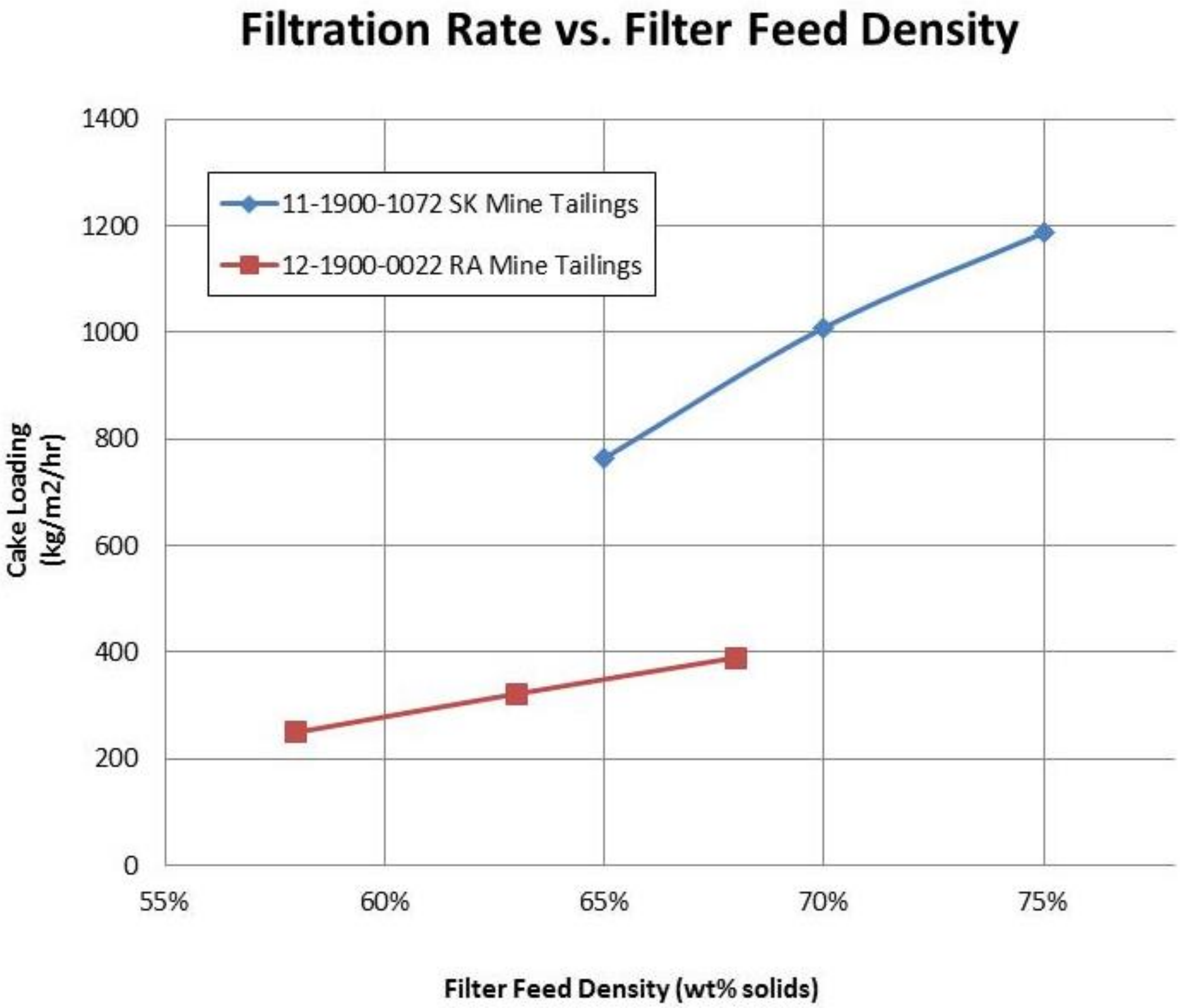

Figure 12 Filtration rates

In addition, the strengths between the two tailings materials were substantially different. Typically, the major contributor to strength differences is the water:cement ratio. Platy minerals with high specific surface area or minerals which absorb water increase the water content at a given slump and the strengths typically decline with larger water:cement ratios. In this case there was a substantial difference in the water:cement ratio between the two tailings at a given slump.

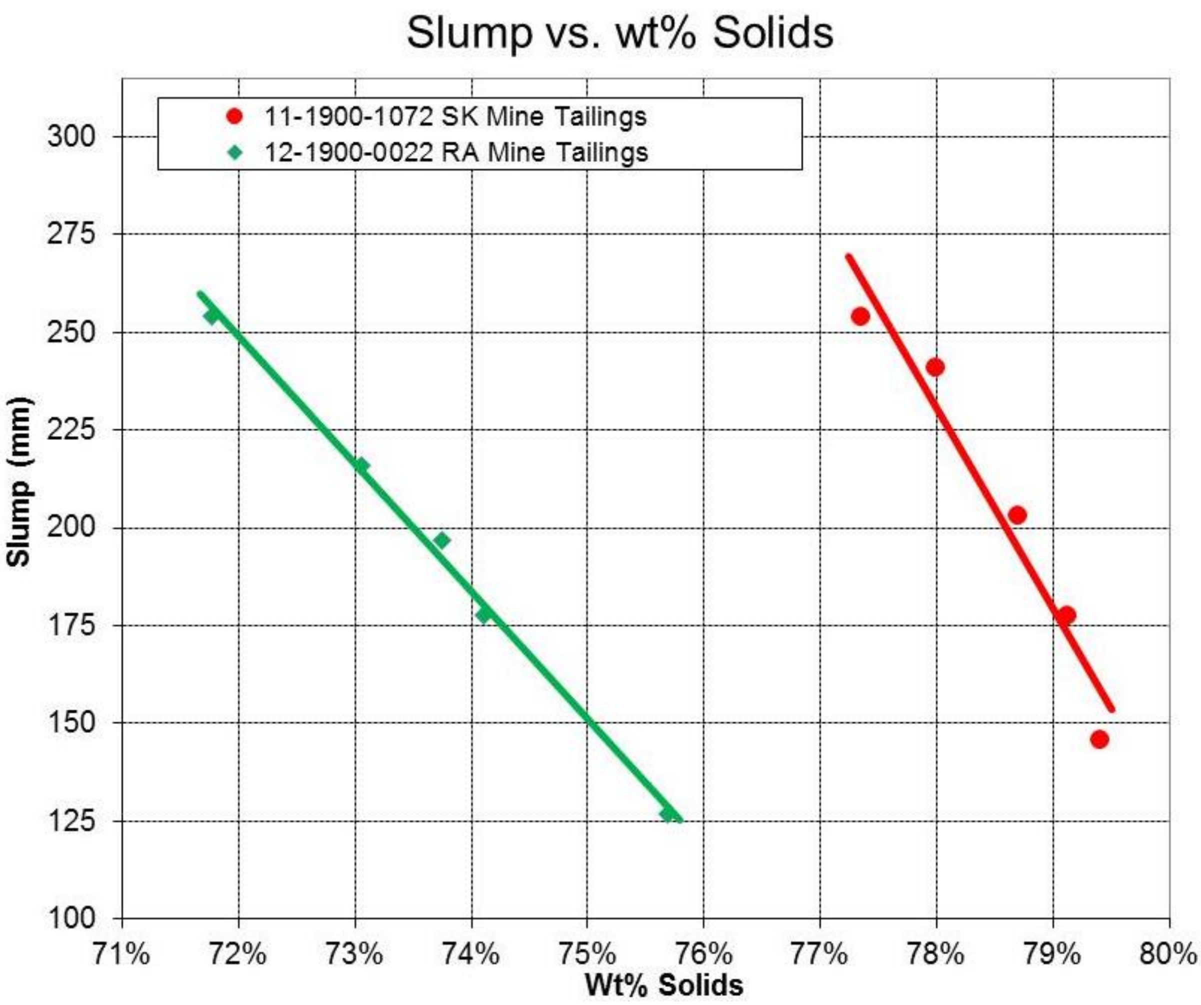

Figure 13 Slump versus solids content

4.2 Underground distribution system

The principal difference in the underground distribution system design between the two mines is that the RA mine has an existing (active) open pit and it is therefore not possible to locate the paste plant above the mine workings. This results in the requirement to pump the paste to the RA mine workings rather than flowing by gravity as is possible with the SK mine system.

This is a major difference in capital and operating cost since the paste pumps are huge.

Table 1 Pump information

Manufacturer	Putzmeister
Pump type	Hydraulic piston pump
Model no.	HSP 25.150 HPS
Operating flow rate	161 m^3/h at 85% filling efficiency
Design nominal flow	185 m^3/h at 85% filling efficiency
Operating pressure	90 bar
Design pressure	120 bar
Rated power	400 kW

In addition the longer pumping distance adds more high-pressure piping and with a longer pipeline there is an increased risk of downtime if there is a system blockage and paste is allowed to cure in the line. The shorter the distribution system, the lower the risk of blockage and the less severe the problem will be if cured paste must be cleaned out of the piping.

The piping design for the pumped system vs. the gravity system is also substantially different. Firstly, the pressures expected in the RA mine piping can reach 135 bar through a combination of the maximum pump design pressure and the elevation head in the first borehole. Although the typical operating pressure at the RA mine will be closer to 90 bar at the pump discharge, the worst case scenario of 120 bar to clear a partial blockage or restart after a stoppage in flow requires a high-pressure piping system. In the case of RA mine the piping selected for the highest-pressure section of the line is a Schedule 80 API 5L Gr. X52 with class 900 flanged ends. This is an expensive and less flexible system; however, due to the loss of pipe wall thickness due to the groove depth using Victaulic couplings, the flanged ends were selected for the highest-pressure areas of the distribution system. Once the piping has reached the top of the workings then some of the lateral piping will be Schedule 40 API Gr. X52 with Victaulic 77 couplings; however, a significant portion of the distribution system is composed of the higher-pressure piping system.

Conversely the SK mine distribution system has comparatively low pressures with normal pressures not expected to exceed 70 bar. This allows the use of Victaulic HP70ES couplings in high-pressure areas of the mine and Schedule 40, API 5L Gr. X52 with Victaulic style 77 couplings in low-pressure areas. The majority of the distribution system is composed of this low-pressure piping which is inexpensive and easier to install.

An additional cost associated with the RA mine distribution system is the level of bracing required to prevent movement in the pipeline. With a pumped system using piston pumps there is a cyclical pressure spike at each cylinder changeover which occurs approximately every 10 seconds. At each changeover there is a pressure wave which propagates through the pipeline and results in water hammer and subsequent pipe movement if not securely braced. With a continuous gravity system there is no significant pressure spike and movement is minimal. Because of this the bracing requirement is substantially less with a gravity system which is a significant cost advantage for SK mine.

4.3 Stope sizes and strength requirements

There is a large difference in stope size between the two mines with SK mine planning on very tall stopes and RA mine requiring short stopes. Despite the difference in stope size the cement content required to meet the strength targets is very similar between the two mines. The cement requirement is dependent on the strength requirement due to the nature of stope exposure and is largely governed by freestanding height.

The stope sizes and strength requirements are shown in Table 2.

Table 2 Stope sizes and strength requirements

Mine	Width (m)	Length (m)	Height (m)	Strength (kPa)	Cement %
SK	30	30	105	1,100	8
RA	15	25	25	370	8

In addition, there is significantly higher opportunity for SK mine to optimise their cement usage by progressively decreasing the cement content with an increase in pour height. Although this is complicated somewhat by multiple plug pours at 35 m level spacing and the ability to reduce the cement content is somewhat dependent on the allowable time for curing the plug pours at the two upper access elevations there is likely the opportunity for significant cement content savings.

Because of RA mines short stopes there is much less opportunity for a reduction in cement content.

4.4 Comparison of technical characteristics

Table 3 Comparison of key technical parameters of SK and RA paste backfill plants

No	Parameters	SK mine		RA mine	
1	Yearly voids to be filled (m^3)	1,000,000 for 3 Mtpa		817,000 Phase I @ 2.5 Mtpa	
2	Target paste production dry (t/h)	401		215	
3	Target paste production wet (m^3/h)	240		161	
4	Mining rate (Mtpa)	2 now; 3 future		2.5	
5	Cement consumption (%)	8		8-12	
6	Target strength (KPa)	1,100		350 longitudinal/ 370 transverse	
7	Mining method	Sublevel open stoping		Long hole open stoping	
8	Specific gravity of tailing sample/solid specific gravity	3.05		2.93	
9	Flow parameters				
	Parameter	178 mm slump	254 mm slump	178 mm slump	254 mm sump
	Paste solid content (wt %)	79	77	74	72
	Yield stress (static Pa)	223	125	400	200
	Viscosity (Pas)	0.9	0.35	0.6	0.32
	Paste bulk density (t/ m^3)	2.12	2.06	1.95	1.9
	Flow rate (m^3/h)	240	251	161	161
	Pipe diameter (mm)	200-250	200-250	200	200
10	Thickener underflow (% wt)	70		58	
11	Flocculent dosage (g/t)	20		40	
12	Filter cake solid (% wt)	83		79	
13	Deposition density to underground (t/m^3)	2.12		1.95	
14	Paste solid content (mixture output) (% wt)	79.1		74.1	

5 Conclusion

The design and construction of two paste plants in India was interesting and involved both challenges and opportunities. Although paste systems are new to almost all of the HZL staff there was a genuine desire to ensure that prior to startup of the plant that both management and operations were well informed and prepared to run the system. HZL's methodology for the design and operation of the paste facility reflected a very professional and thorough approach to the introduction of new technology into their operation. It will be very interesting to see how the preparation and training affects the startup and handover of the system.

The differences between the two systems are substantial and it is hoped that this example can be used by other practitioners to illustrate the wide range of plant requirements and costs when confronted by those who believe that all paste systems are the same.

At the time of writing this paper (October 2014) the SK paste system was partially commissioned and had produced paste (without cement) of 250 mm slump. The RA mine system construction has been completed; however, commissioning is being delayed until the first underground stope is ready in 2015.