ESSENTIALS ON IN-PIT CRUSHING AND CONVEYING (IPCC)

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ABSTRACT

In-pit crushing and conveying (IPCC) is generally applied in three configurations: fully mobile, semi-mobile (including semi-fixed), and fixed.

In fully mobile systems, shovels/excavators, feed crushers, direct and trucks are confined to a clean-up fleet. Crushers are mounted on tracks and move with shovels. Connecting crushers to a main conveyor requires mobile belt wagons, mobile bridges or link conveyors.

For semi-mobile IPCC systems, the crusher stations are located near the working face, requiring small (in number) truck fleets shuttling between shovel/excavator and crusher. Crushers can be relocated regularly to keep pace with an advancing face (vertically or horizontally) or relocated strategically (e.g. once every 3–10 years).

In fixed IPCC systems, the crusher stations are away from the actual mining face, often placed on or near the pit rim, leaving the trucks complete flexibility inside the pit. Semi-mobile and fixed IPCC systems could be easily retro-fitted into existing open pit operations without major redesign or rescheduling of the pit.

In-pit crushing and conveying (IPCC) could gradually substitute most pit haul trucking operations, but many mines delay conveyor installation beyond the ideal date for change. In >85% of studies, comparing IPCC with truck-optimised pit designs, conveying still generates large operating savings. Conveyors are much more capital and energy efficient on large operations, cheaper to operate per tonne moved, and require low technical maintenance. In-pit crushing also reduces haulage road development and maintenance needs.

This paper deals essentially with aspects of conveying in IPC applications but the underlying message is that the logic, reliability and capability of conveying to move vast volumes of material can be successfully applied to function effectively inside the mining pits, not just in processing plants.

Safety first

Talking/writing about environment, health and safety topics reminds people of safety issues and as a result, they start becoming more safety conscious.

The U.S. Department of Labour reported 182 injuries during the first three-quarters of 2012 attributed to haulage in surface mining. Injuries involving mining trucks were 102 (56%), 44 (24%) were related to front end loaders and 36 (20%) of these 182 injuries referred to all other powered haulage including conveyors[1]. Every one of these injuries is one too many, nevertheless these figures clearly show the safety advantage of conveyors and conveying systems when safety precautions are implemented in mining operations.

INTRODUCTION

In surface mining, the operational costs for haulage alone may account for up to 50% of total operating mining costs (Opex). The percentage of total capital invested for haulage is even higher (road maintenance graders, water trucks, dozers, etc.) and is said to be up to 60% of all mining capital expenditure (Capex). These figures vary slightly from mine to mine and commodity to commodity, but one thing is clear: transport is a major cost factor in mining, and every effort has to be taken to optimise haulage, especially in modern mining operations where millions of tonnes of different materials have to be moved in several directions using many methods. Table 1 shows a textbook example of typical surface mining costs.

CAPEX	$	
Drilling/Blasting	1,3	10,8%
Loading	3,6	30,0%
Haulage	7,1	59,2%
Sum	12,0	100,0%
OPEX	$/ton	
Capital cost	0,6	33,3%
Drilling/blasting	0,3	16,7%
Loading/Haulage	0,8	44,4%
Auxiliary	0,1	5,6%
Mining costs	1,8	100,0%

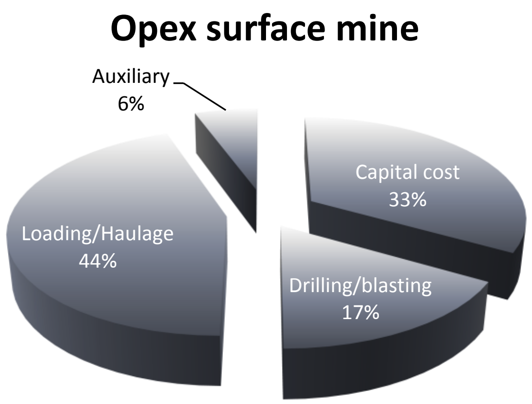

Table 1. 1988 cost estimation of a 4,5 Mtpa surface mine. Capital cost @10% discount[1]
(SME Mining Engineering Handbook)

Why is transportation that expensive, and is there a way to decrease haulage costs? To answer this, it is necessary to go back to basic physics.

$$E = mgh = 1000 \text{ kg} * 9{,}8 \text{ m/s}^2 * 1 \text{ m} = 9{,}8 \text{ kJ} = 2{,}72 \text{ Wh}.$$

It is not possible to use less energy to lift something up on this planet. Converted into money and assuming that one kWh of electrical energy costs about 0,07 US$, this means lifting one tonne costs a minimum of 0,02 $-cents per metre, assuming that any other losses are nil – which they are not. To move this mass by conveyor requires knowledge of a whole host of data (including, but not limited to, speed, belt type, length, gradient, idler and pulley configurations, material bulk density, etc.), but at the end of the day the only extra weight it has to lift is parts of the belt itself. Compared to this, minimum operating costs of lifting by a diesel engine driven mining truck (with its own empty weight mass) at a fuel price of 1,1 US$/litre will be more than double that of a conveyor.

Two main sources of losses in haulage can be identified: Here they are called “tare” and “drag”.

Tare is the additional weight of the equipment/machinery required to move the metric tonne vertically by one metre. Drag is the additional force that acts against this transportation like friction, inertia and counter-induction. In addition, a combustion engine can only transfer <50% of the chemical potential energy stored in fuel into mechanical energy, with mining trucks accounting for only an estimated 25–35%[4]. In the case of trucks, this small amount of converted energy then has to bear further drive train losses before moving the actual tyre which then encounters the road surface drag items above.

The task in engineering is to find a way of transportation as close to the physics limit shown above as possible. Reducing tare can be done in two ways. One is to find structures or materials that are very light, the other possibility is to utilise the transport vessel more efficiently.

Conveyors in mining make use of both solutions, as the only tare to be moved is the weight of the belt itself in addition the mass being moved. However, with more than obvious cost/energy benefits, why has the mining industry not adopted the system of conveying inside the pit? The answer: the industry is familiar with trucks; does not like change; there is no commercially operating mine planning software for conveyors, yet packages abound for truck scheduling (e.g. Surpac, Xpac, Vulcan, Orelogy, etc.); conveying is not taught as a mining haulage alternative at most mining engineering universities; and lastly, conveyors are seen as an inflexible system within a changing environment which is a disadvantage that can be overcome by an IPCC installation. The big difference between truck haulage operations and conveyor haulage operations inside pits is that the conveyor operation has to follow the plan or will fail whilst the truck operation can more easily ignore the plan (e.g. chase high grade as required for altered commodity cycles).

TYPES OF IPCC

IPCC includes loading, crushing, conveying and dumping. Loading of the IPCC installation is done by conventional shovels/excavators or by trucks. Crushing in most cases only has the purpose of reducing the feed to conveyable size, which means a maximum particle size smaller than 20% of the belt width and a maximum of 350 mm-sized grains due to the high impact energy of bigger particles and the interlocking of larger particles at conveyor transfer points, leading to potentially massive blockages and associated downtime if larger than 350 mm. At the end of the IPCC system, a spreader distributes the mined material to a dumping site or it is directly fed onto a stock pile.
When designing an IPCC system, one of the important choices lies in selecting the front end of the IPCC installation. Three primary types of IPCC should be looked at here:

- Fixed crusher within the IPCC system
- Semi-mobile or semi-fixed crusher within the IPCC system
- Fully mobile crusher within the IPCC system

The crushing station of a **fixed IPCC system** is usually situated at the pit rim, a location not affected by mining, or outside the perimeter but fairly close to the pit. This is very different to having a fixed ore crusher, which accepts run-of-mine material at the front end of the processing plant. It is usually designed to last a lifetime in a fixed location and is never be moved to another site. The overland conveyor line which transports crushed material from a fixed crushing station is a fixed installation as well. Between the crusher and the overland conveyor is a favourable place to install a short belt conveyor – called a sacrificial conveyor – in order to protect the long overland conveyor from damage caused by metal pieces that passed through the crushing station. Mining trucks usually feed the crusher. Figure 1 shows an example of a fixed crushing station.

Figure 1. Fixed crushing station

The idea of **semi-mobile IPCC systems** is to situate the primary crusher in the pit as close as possible to the mining face. This enables the mining operator is to reduce the number of trucks to a minimum, while retaining the fleet's high flexibility level[5]. Behind this lies the principle of reducing transported weight. A truck carries more than 35% of its own weight. This is already a disadvantage on a flat plane but it becomes a costly problem when transporting up a ramp. With semi-mobile stations, this can, to a large extent, be avoided as long as there is a suitable location in the mine to place the crushing station for at least several months, preferably longer, to about one to three years. After this period the entire station can be moved to another location. This only takes a few days using a crawler, because of the modular construction and the fact that usually no concrete foundations or other sophisticated civil construction works are needed[6,7].

As the crusher would then be situated in the pit, conveying strategies have to be developed to transport crushed material out of the pit. Semi-mobile crushing stations can be equipped with various crushers. Predominantly, roller crushers and gyratory crushers are used. Jaw or impact crushers may also be used in smaller capacity (<1000 t/h) crushing-plants. Currently, the maximum capacity of all crushing plants is determined by the feed rate. The largest primary crushers are designed for throughputs exceeding 10 000 metric tonnes per hour. The station's hopper can be fed by trucks from up to three sides simultaneously. However, the bottleneck is the physical dumping time of the trucks according to traffic flow rules per any given hour and is presently limited to a maximum throughput of 10 000 t/h. On the other hand, it is easily possible to use one conveyor line to handle the output of more than two semi-mobile crushing-stations at once. Figure 2 shows two of four semi-mobile waste crushing stations at a lignite mine which process 5 500 t/h each.

Figure 2. Semi-mobile crushers feeding one overland conveyor

Fully mobile IPCC-systems consist of a crawler-mounted crushing station, usually fed by a shovel. These stations can be equipped with a roller crusher or a jaw crusher. The use of gyrators was not possible until recently, since the high horizontal forces needed to be addressed. The crusher follows the shovel as the face advances and therefore a movable conveyor segment connecting to a track-shiftable bench conveyor is needed. In many applications a movable, self-levelling conveying bridge is advantageous as it is lighter in weight and tracked at each end, giving greater flexibility than a belt wagon. A fully mobile system completely eliminates the need for mining trucks and therefore has a much greater potential to lower the operational costs over the other two types of IPCC systems. The key to success in IPCC is following the mine plan, and accepting that IPCC is not as flexible as trucking, but that operational costs could be halved. The bottleneck of fully mobile stations is the shovel's performance. Here the maximum capacity in the near future will be an electric rope shovel with a maximum bucket volume of 70,3 m^3 and 120 t of payload[8]. This shovel is expected to realise a long-term average loading performance of about 9 000 t/h.

Fully mobile systems can be used in different ways which have to be determined in advance by the mining plan. When using a conveying bridge together with a fully mobile station, up to three benches can be mined out before the bench conveyor has to be moved. This ability substantially increases effective operational hours of use since the bench conveyor requires less track shifting.

All primary equipment used in a fully mobile IPCC operation is electrically driven (crushers, conveyors and discharging devices), thus reducing CO_2 production and increasing the power efficiency. Figure 3 shows a fully mobile station equipped with a roll crusher processing onto a belt bridge that is linked to a track-shiftable bench conveyor.

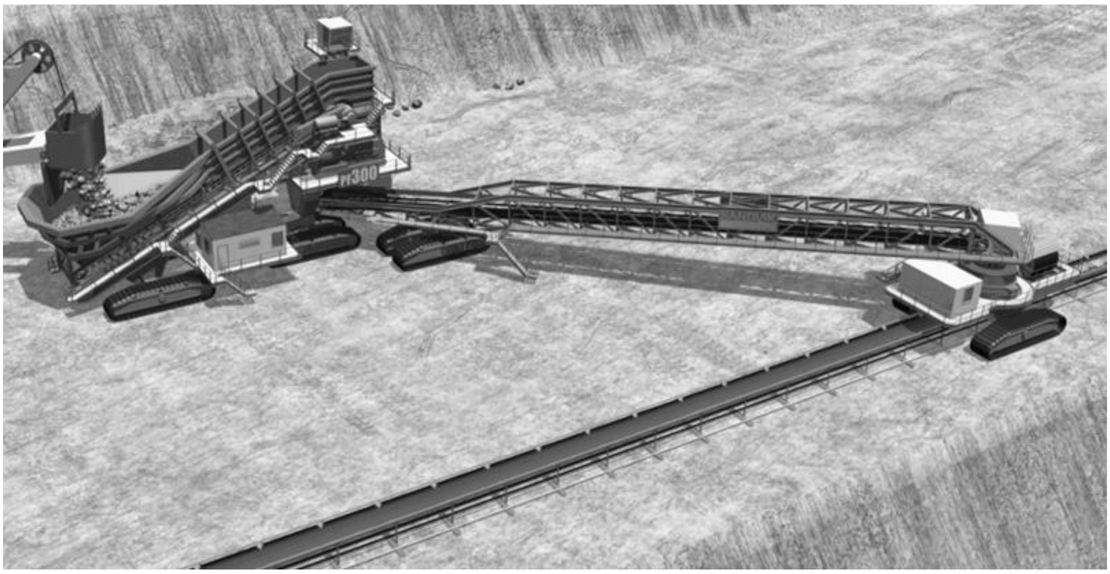

Figure 3. PF300 fully mobile crushing system consisting of a loading shovel, the mobile crusher, a belt bridge and a track-shiftable bench conveyor

PIT-EXITING STRATEGIES

When crushing is done inside a pit (and of course in underground mines as well, but this paper focuses on surface mining), long-term strategies have to be developed as to how and where the crushed rock exits the mine. In some mining applications this is obvious and supported by data from similar operations, but in many cases this can be difficult due to – amongst others – the following factors:

- Deep pits meaning high vertical advance rates to overcome
- Very high capacity conveying needed (meaning only conventional conveyor belts can currently be used – not "sandwich" conveying)
- Different qualities of materials to be conveyed on separate lines without mixing
- Rapid advance of the pit face which make long-term ramps for installations difficult to plan
- Different dumping locations (plant, dump, stockpile) result in more conveying-routes

Looking down a deep pit, three obvious methods of exiting the mine can be identified:

- Conveying on existing truck ramps
- Conveying on a designated conveyor ramp
- Conveying through one or more designated tunnels

Making the correct decision during the planning stage is not only a technical but also an economic challenge. Trucking ramps – although an obvious conveying route when adding conveyors to an existing mine – are often limited to a gradient of 10%. This lengthens the conveying route in comparison to a conveyor ramp that from a practical viewpoint, be built up to 25% (consider ease of maintenance, but theoretically can be up to 18 degrees without material roll-back issues) and thus shortens the needed conveyor length by at least 2,5 times. But not only is the belt conveyor's length shortened; the power demand is reduced as well by this and other reasons like the decrease in friction between conveyor belt and idlers/frames, fewer idlers resulting in lower rolling resistance and less belt indentation. In Figure 4 the dependence of operational power versus inclination is shown for an elevation of 100 m at different belt speeds and a conveying rate of 10 000 t/h.

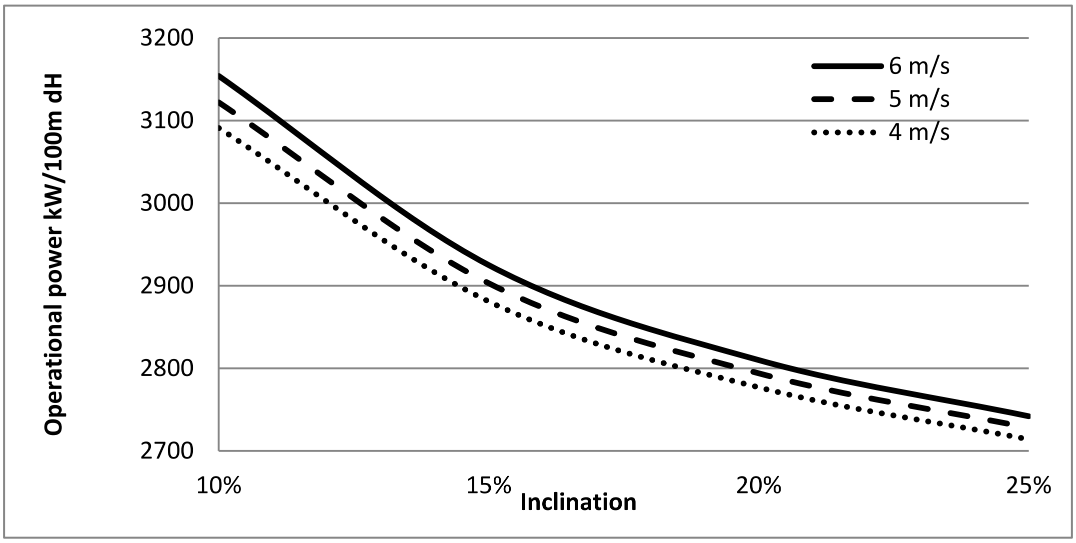

Figure 4. Power demand for 100 m lifting at 10 000 t/h

It can be clearly seen that at 25% inclination only about 85% of the operational power(cost) is needed compared to an inclination of 10%. (The installed power for conveying will be somewhat higher due to peak power demands, mainly caused by starting the conveyor under full load in case of an emergency stop for example). Moreover, a shorter conveyor line reduces the capital expenditure and also the operating expenses. These three cost arguments have to be individually balanced against the effort of not only building a steeper ramp but ensuring effective drainage control (consider hydraulic head of water flow at base of a steep ramp). Figure 5 shows a ramp conveyor exiting a copper mine in the U.S.

Figure 5. Ramp conveyor at a copper mine, Arizona. The difference in inclination between a truck ramp and an IPCC conveying ramp is clearly visible

Conveying through tunnels is a viable alternative especially for deep open-pit mines. The conveyor is out of sight and does not consume space within the pit shell. Obviously, a tunnel is a fixed building so the mine planning has to be very dedicated to this flexibility-reducing fact. When blasting near the tunnel, support is required inside. Near the pit shell the tunnel should be built at a horizontally steep angle towards the mining face to ease the pushback-operation at the tunnel entry.

Figure 6 shows a conveyor tunnel exit configuration as built at a copper mine in Northern Europe (note flat topography).

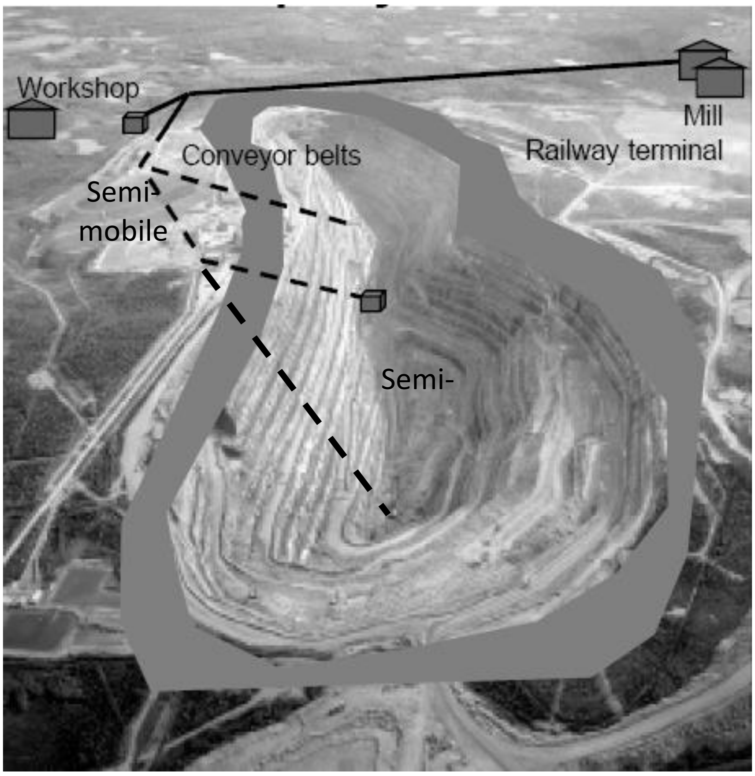

Figure 6. Conveying exit tunnels

Aside from these conveying strategies, other aspects of surface mining include:

- Vertical transport through shafts
- Cable cars, rope conveyor, rail conveyor, etc.
- High angle (sandwich) belt conveyors

None of the above have been developed for high capacity demands (i.e. >2500t/h in a re-locatable environment) leaving the task of high angle, high capacity conveying still partly unsolved.

CURRENT DEVELOPMENTS IN CONVEYING – DIRECT GEARLESS DRIVES

In the past, high torques at relatively low speed forced mining systems suppliers to use gear boxes to drive conveyors. Gearless drives are a new alternative and an attractive solution for conveyors with higher power requirements. Due to its "simple" construction, a gearless drive system has very high availability, robustness, reduced operating and maintenance costs and reduced noise, whilst still offering the benefits of a variable speed drive.

Direct gearless drives consist of a slow running synchronous electric motor coupled onto the drive shaft of the conveyor pulley, a mechanical safety brake and a frequency converter. Hence there are no transmission ratios, gear bearings, fluid couplings and other mechanical parts that can wear out. In case of downwards conveying, the use of direct drive technology easily enables operators to regenerate and provide electrical energy to the local grid, contributing to even lower operational costs. Figure 7 shows the principle of direct gearless drive technology.

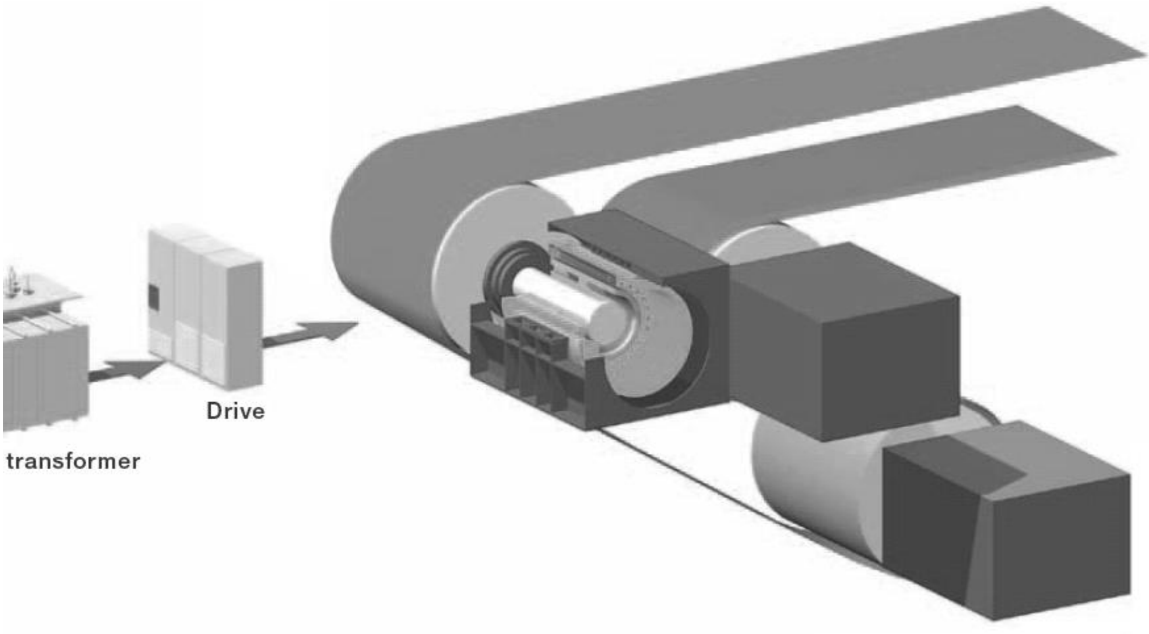

Figure 7. Principle of direct gearless drive technology
(Courtesy: ABB)

Currently there is only one large gearless drive in the field that has been operating for longer than one year. This is a conveyor drive at the Prosper-Haniel coal mine in Germany which was installed in 1985. Several more projects are however, soon to be completed.

Gear reducers that have traditionally been used to drive conveyors are reaching their physical limits for demanding applications, such as steep angle or high capacity installations. At present, a modern conveyor system with a total drive power demand of 15 000 kW or more would require over six traditional gear reducer drives, each equipped with >2 000 kW motors. The traditional gear reducer solution has the disadvantage of reduced overall availability associated with the large number of mechanical components (bearings for each of the gear boxes), which result in a smaller Mean-Time-Between-Failures (MTBF). Furthermore, gearless drives reduce maintenance costs and reduce efficiency losses caused by gear boxes, making them intrinsically more reliable[10]. The actual limit of gearless drives are defined by the belts currently being fabricated at a minimum breaking strength (i.e. ST10000).

The turnover point for the economically reasonable implementation of gearless drives is said to be at about 3 000 kW. Mining companies are striving to reduce energy consumption, CO_2 emissions and increase system reliability. Gearless drives meet these requirements by significantly reducing the number of mechanical components, such as gears, bearings and couplings. The environmental footprint of a gearless drive installation is approximately one third of a conventional geared system.

SUMMARY

In-pit crushing and conveying have different variations. Fixed and semi-mobile crushing stations fed by mining trucks provide some flexibility while fully mobile, truckless mining applications probably lead to the highest cost savings but need very detailed planning upfront. Which form of IPCC suits an individual mining operation has to be assessed by specialists who have actual knowledge of a successful IPCC operation. At the end of the day, trucks will always have a place in mining, however, with over 200 world-wide operational IPCC sites today showing the way, the mining industry has the ability to choose an alternative mining method (IPCC) that delivers on cost savings. Conveyors in the pit are believed to be the way forward to deeper pits, lower grades and reduced operational costs. Modern conveyor drive techniques like gearless drives can additionally enhance the economic value of IPCC.

REFERENCES

1 U.S. department of Labour. Mine injury and work time, quarterly, January – September 2012, pp18, pp31.

2 Mukhopadhjay A. Selection, maintenance, and relations of various parameters for off-highway hauling tires. In: Off-Highway Haulage in Surface Mines, Ed. Golosinski, Sraje, Balkema, 1989, pp 153-159

3 Hartman H.L., ed. SME Mining Engineering Handbook, 2nd edition, Vol. 1, 1992 p. 2061.

4 Raaz V., Mentges U. Ermittlungsverfahren für Energieeffizienz und CO^2 Emission der unterschiedlichen Tagebautechnologien. Proceedings of the 15th Fachtagung Schüttgutfördertechnik, Munich, 2010.

5 Morris Ph. The renaissance of in-pit crushing and conveying (IPCC), Sandvik.

6 Oberrisser H. Fully mobile crushers as part of total IPCC solutions. In: Proceedings of the Mining Magazine Congress, 8./9. Oct. 2009, Niagara-on-the-lake, Canada, p.7.

7 Mentges U. Relocation of semi-mobile crushing plants in Indonesia and China. Surface Mining Braunkohle & Other Minerals, Vol. 55 (2003) No. 3 (July / September), p.237-243

8. JoyGlobalwww.phmining.com/JoyGlobal/NewsReleases/JG/4800XPC_News_Release_MINExpo_2012_web_vers.pdf, downloaded on Jan 24th 2013.

9 Sandvik: PF300 - Essential part of In-pit crushing and conveying (IPCC). www.youtube.com/watch?v=doNcVs-APvY.

10 Meakin L., Saxby P. Design fundamentals for drive systems on conveyors. In: Australian Bulk Handling Review, March/April 2009, p 25.

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