# HIGH PRESSURE GRINDING MOVING AHEAD IN COPPER, IRON, AND GOLD PROCESSING

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**ABSTRACT**

High Pressure Grinding Roll ("HPGR") technology is applied to an increasingly diverse range of applications, predominantly iron, gold and diamonds. KHD Humboldt Wedag HPGRs are applied world-wide, and do consistently prove to be well designed and reliable operating units, with their performance meeting the pre-set standards. This publication summarizes some of the features and experiences for recent applications in treatment of copper ore, coarse iron ore, and gold ore. Summary data of roll surface wear life and operating data are given, together with operational observations. In addition, effects of feed segregation and truncated feed are discussed, and implications of a product recycle flow sheet.

## INTRODUCTION

HPGRs (High Pressure Grinding Rolls, also known as Roller Presses) are becoming well accepted for coarse and hard rock applications, especially for abrasive conditions. When the first HPGR in coarse ore was commissioned at Los Colorados in 1998, there were only 14 HPGRs installed in the minerals industry, mainly for grinding pellet feed to increase the Blaine value [Van der Meer et al., 1997], and only three KHD HPGR units were applied for crushing coarse ore. Nowadays, well over 100 HPGRs have been or are being installed in ore processing applications, and this number is expected to grow rapidly in the years to come.

The Los Colorados plant of CMH in Chile was the first successful operation in which an HPGR was used to replace a conventional tertiary and quaternary crusher. At that time HPGR technology was considered new to this type of installation, and extensive test work and studies were conducted to support the plant design. The grinding circuit was designed to include primary gyratorycrushing, secondary conecrushing, and a Humboldt Wedag HPGR Type RP 16-170/180 (roll diameter 1.7 m, roll width 1.8 m) in place of a tertiary crusher operating in closed circuit with vibrating screens to recycle the oversize +7 mm fraction back to the HPGR circuit. The 7 mm undersize is fed to dry magnetic separation. The capacity of the HPGR is about 2,000 t/h.

Vasilkovka Gold Mining is one of the recent applications in gold ore treatment in the North Kazakhstan Region. Its ore has a high concentration of copper which significantly complicates gold extraction. The Vasilkovskoye mine is estimated to contain 400 tonnes of gold. In this gold plant, two Humboldt Wedag HPGRs Type RP 16-170/180 (roll diameter 1.7 m, roll width 1.8 m) are operating in parallel since 2009, each in closed circuit with a partial product recycle, at a capacity of about 1,200-1,400 t/h.

At the Nurkazgan copper plant of Kazachmyss, Kazakhstan, two HPGR units Type RP 13-170/140 (roll diameter 1.7 m, roll width 1.4 m) are operating in series, each in closed circuit with a partial product recycle and a closing 5 mm aperture screening. The units effectively perform the duties of tertiary and quaternary crushing stages, and were commissioned at the end of 2007. The units have a capacity of about 900 t/h, at a product recycle of approximately 75 % - 125 % (effective recycle mass in proportion to fresh feed) for an initial feed top size of 35 mm. Ultimate product size is 80 % < 0.8 mm, with up to 60 % < 74 µm, at a specific power consumption of 1.8 to 2.2 kWh/t.

## 1.0 LOS COLORADOS OPERATION IRON ORE

The crushing and pre-concentration plant is located near the mine. After rail transport to the pellet plant, the magnetic pre-concentrate is ground in ball mills to pellet feed fineness and further concentrated by wet magnetic separation. Figure 1 shows a schematic flow sheet of the Los Colorados HPGR circuit.

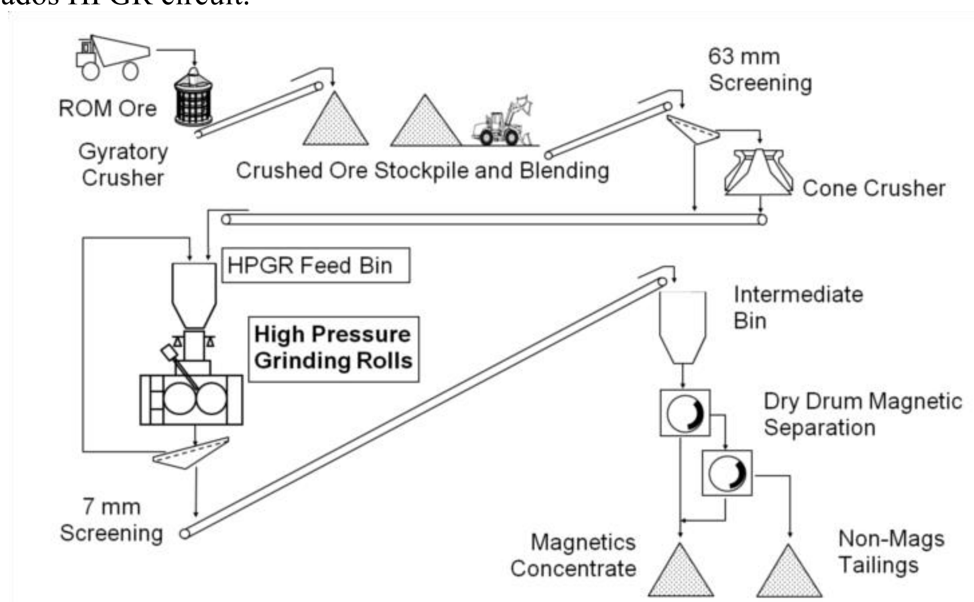


Figure 1: Simplified flow sheet of HPGR based circuit at Los Colorados / CMH, Chile

### 1.1 Operating Experience at Los Colorados

The positive findings and downstream benefits observed in pilot testing paved the way for a successful installation of a HPGR at the Los Colorados plant (Table 1), with the confidence that the unit would meet expectations in full scale industrial operation.

Table 1: Operating data of HPGR at Los Colorados/CMH, Chile

| **HPGR model:** | | **RP 16-170/180** | |
|---|---|---|---|
| Roll type: | Shrink-fit Tyres | Feed size: | 0-45 mm |
| Roll surface: | Stud lining | Product size: | 55-70% < 6.3 mm |
| Roll width: | 1,800 mm | Feed moisture: | 0-1% |
| Roll diameter: | 1,700 mm | Specific energy: | 0.8-1.2 kWh/t |
| Feed material: | Coarse iron ore | Motor size: | 2 x 1850 kW |
| HPGR throughput rate: | Up to 2,000 t/h | Ball mill Wi before HPGR: | 9-14 kWh/t |

The Los Colorados Huasco pellet plant reported lower energy consumption in wet ball milling, as well as reduced circulating load in the mill circuits, due to a finer feed and improved Bond Ball Mill work index. The existing ball mill capacity could be increased by 30 %.

### 1.1.1 Wear life

Based on test results the wear life was guaranteed at 12,000 hours initially. The roll surface, as main wear component, met the guaranteed wear life right from the beginning. This was possible because of good compaction of the ore on the stud-lined surface. The quartz content was about 15% during pilot testing and today varies between 15-30% according to ore type. Three factors affect wear most: quartz content, operating pressure and quality of compaction of the autogenous wear layer between the studs on the roll surface (Figure 2). Of these, formation of a competent autogenous layer can make a huge difference in achievable wear life [Dunne et al., 2004]. For example, when treating taconite material (excess pebbles from a fully autogenous mill circuit) at Cleveland Cliffs´ Empire Mine a wear life of up to 17,000 hours was achieved even though the machine was operated at a high specific pressure of 4.5-5.0 N/mm² and the quartz content of the ore averaged near 37% [Rose et al., 2002, Dowling et al., 2001, Maxton et al., 2006].

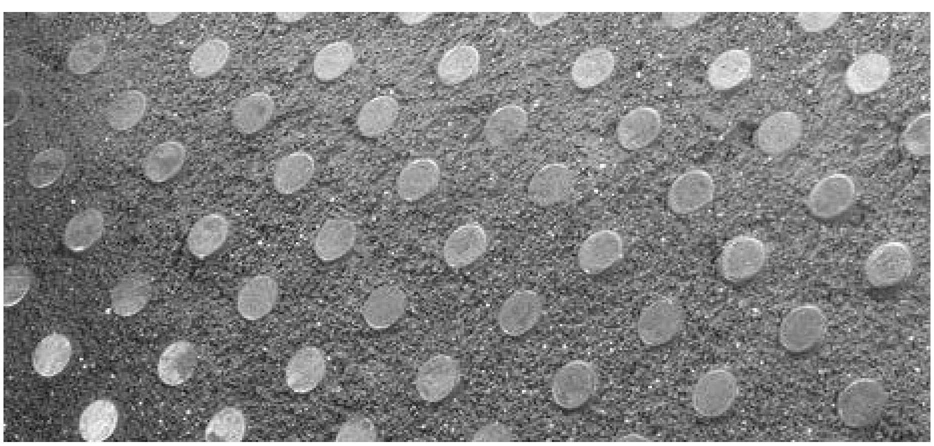

Figure 2: Picture of a compact autogenous wear layer in-between studs.

Obviously, the roll surfaces are the most critical parts of the HPGR, in terms of performance and investment. An accurate prediction of wear life of the roll surface during operation is essential since this is the single largest factor which determines operating cost. It can determine whether a project is viable or not. Each manufacturer has developed its own in-house wear rate test suitable for its proprietary surface. The Humboldt Wedag wear rate tests were developed over the past decade. The result of this test is a wear rate index which is correlated to operating data of the Humboldt Wedag units in minerals operations. The test provides an accurate and reliable specification of wear rate data as basis for process guarantees for minerals applications.

Wear increases with pressure, thus reducing operating pressure would lead to a longer roll surface wear life. Pilot testing determines how product size is affected by operating pressure, and provides a basis to balance between operating pressure and power consumption, generation of fines, and wear rate. There generally is a level above which additional pressure results in an excessive energy consumption, and a disproportional increase in the generated fines [Van der Meer et al., 2008]. This is attributed to a lower incremental size reduction from a denser particle bed and higher relative proportion of fines within the bed. At Los Colorados it was observed that a decrease in pressure resulted only in a small increase in circulating load. Overall, operating at lower pressure than initially commissioned (2.5-3.0 N/mm² instead of 4.0-4.4 N/mm²) proved to be advantageous, especially when considering the overall energy consumption of the HPGR circuit.

During the life of a set of tyres, wear measurements are taken periodically at, say 2 months or longer intervals. Figure 3 shows the typical wear profile for coarse ore operations. This illustrates the progress of wear of surface expressed in millimetre of depth over the width of the roll. A total of 58 positions were measured, on 4 locations over the rolls‟ circumference (at 0°, 90°, 180°, and 270°). Eight measurement series are shown; one base-line of the new roll surface after installation, and one series each for 2, 4, 6, 8, 9, and 10 months of operation. The measurements indicate a moderate wear over 10 months of operation, in a pattern that is specific for the CMH coarse ore operation (other ores may show a different pattern, such as a "bath tub" profile). The end of the useful life for the rolls in the above example would be reached at about 25-30 mm wear, still some months away.

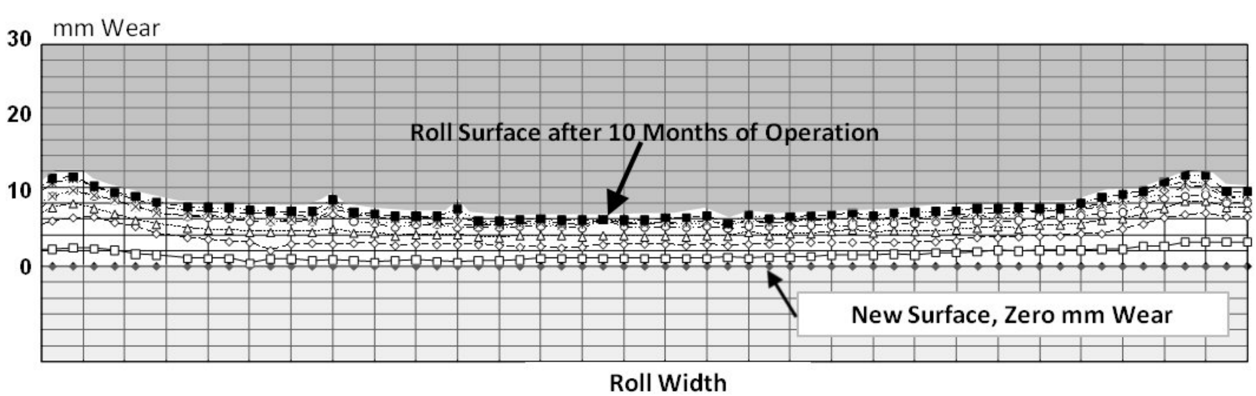


Figure 3: Typical wear profile of coarse ore operations

As shown, the shoulders of the rolls started wearing faster after two months of operation, and over the subsequent 8 months. This higher wear leads to an uneven gap and lower pressure at the sides of the roll where the material is crushed less efficiently and may even partly bypass the rolls.

Eventually, a situation is reached where local wear increases due to the abrasive action of material bypassing the rolls at the edges. To overcome this problem for the next set of rolls (after wearing-out the existing ones) Humboldt Wedag introduced a stud pattern with a modified distribution of stud hardness over the roll width, with harder studs nearer to the edges and harder lateral studs (which facilitate embedding an autogenous wear layer all the way up to the rim of the rolls). Such a continuing improvement of the roll surface design leads to a prolonged roll surface wear life. An example of improvement between roll set #2 and roll set #3 is show in Figure 4. This illustrates that for a wear of 16 mm on the studs, the roll set #3 could treat 3 Million tons additional ore [Barrera, 2005]. In total the studs can wear at around 40 mm.

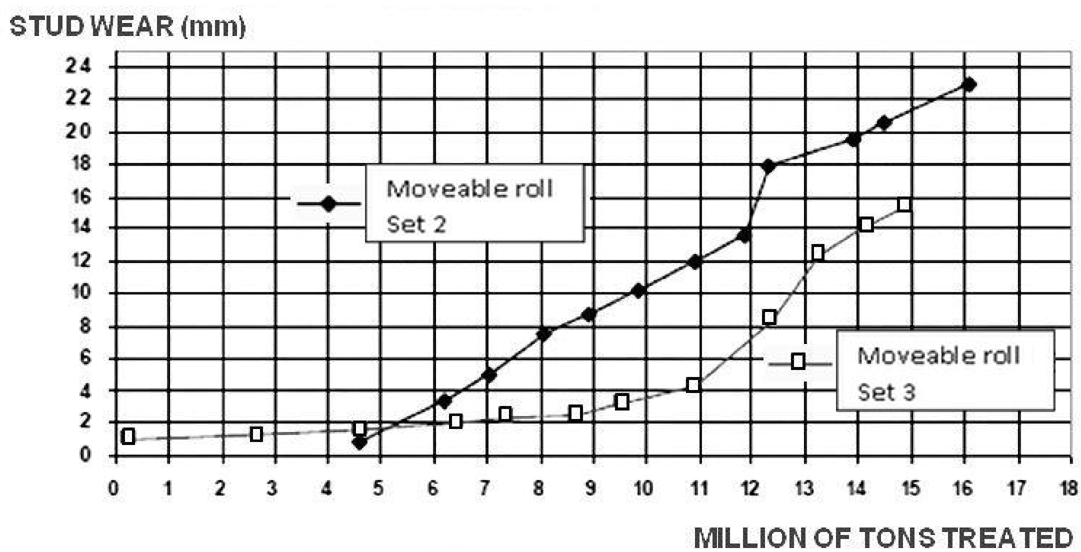


Figure 4: Stud wear vs. tons treated, roll sets #2 and #3

Measures such as described above lead to an increase in wear life at Los Colorados, which today is reported to be at about 14,600 hours.

### 1.1.2 Availability

When designing a HPGR circuit, matching capacity and availability with upstream and downstream crushing and grinding equipment is essential. The capacity of a HPGR can be varied by applying variable speed drives, as throughput is generally more or less proportional to roll speed.

The improvements, modifications and increase in experience on part of the maintenance crew at Los Colorados resulted in an availability of well over 97%. This correlates with the Humboldt Wedag HPGR installed at Argyle Diamonds, Australia where the availability over the last 7 years is reported to be around 96% [Maxton et al., 2002, 2003, Gerrard et al., 2004].

In coarse ore operations, care has to be taken in the design of the materials handling facilities around the HPGR circuit in order not to create bottlenecks that would have a negative effect on HPGR performance. Adequate tramp metal protection as well as appropriate feed bin capacities ahead of the HPGR are prerequisites to ensure uninterrupted choke fed conditions at all times. A proper protection against tramp metal in the feed, both by a self-cleaning magnet above the belt conveyor feeding the HPGR, and metal detector must be installed. The metal detector system, as a safeguard against non-magnetic metal components, must provide a fast response to activate a tramp metal rejection system. Various systems are available, including some that can be operated reliably with iron ore. The best arrangement involves metal detection right in front of the HPGR feed bin. The design may be such that the metal detector activates a bypass flap gate that diverts the metal containing portion of the feed stream to a chute or to a separate bin.

Minimizing downtime during roll changes would require two complete roller assemblies of a shaft with tyre and bearings, each of which is a long delivery item. The exchange procedure then becomes a simple matter of opening the frame, extracting the worn set and installing the new one (as shown in Figure 5 for a present design unit). Depending on site conditions the time required is approximately 24 to 36 hours [Maxton et al, 2005, 2006]. The worn set is then refurbished off-line and serves as ready emergency spare in case of accidental failure.

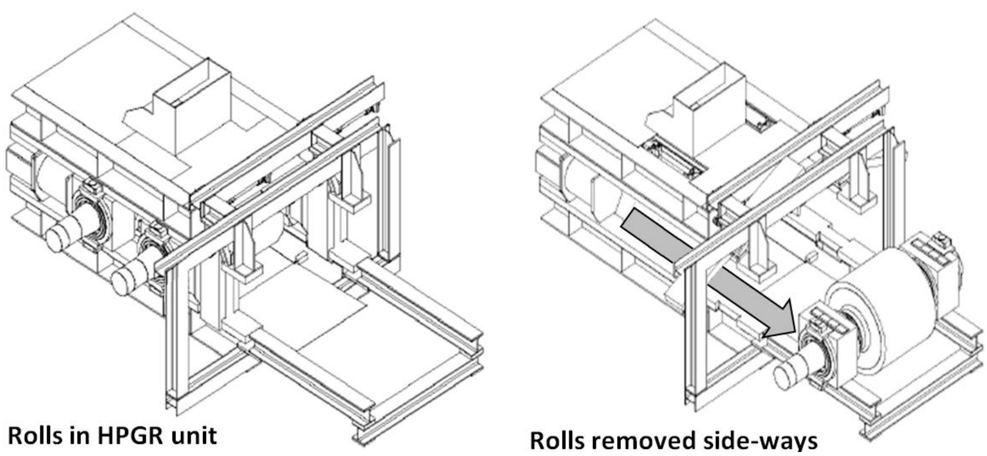


Figure 5: Humboldt Wedag RP S frame design

A standard supply of parts for commissioning and operation is generally provided with the machine. However, minimizing the capital locked-up in critical or strategic spares, while still ensuring an operational continuity may differ for each individual mine site. For Los Colorados a complete set of spare roller assemblies was purchased with the machine and the bearings and shafts of these have been operating successfully since 1998. It should be noted that no premature bearing, shaft or tyre failure has ever occurred at the Los Colorados operation, or at any Humboldt Wedag HPGR in a minerals application overall. To a large part this is the success of the closed circuit oil lubrication system and the patented support concept utilizing a rubber pad to distribute the forces evenly onto the whole bearing (see Figure14)

**1.1.3 Influence of HPGR on downstream processes**

The positive influence on wet ball milling demonstrated in testing was also observed in full scale operation. For example, in ball milling a 27%-44% increase in capacity from about 203 t/h to between 254 t/h and 295 t/h was obtained, depending on ore type, for the same applied energy consumption of 4 MW, when grinding HPGR material to a ball mill product of 80 % passing 44 microns [Westermeyer at al., 2000, Gallardo, 2007]. This was attributed to both a higher fines content and the generation of micro cracks in the particles. The Bond Ball Mill Work Index reduced from 11 kWh/t to between 8 kWh/t and 9 kWh/t, depending on HPGR pressure applied. In magnetic separation, a higher quality pre-concentrate at constant yield was achieved. Both of these effects can be attributed to the same two factors: the generation of more fines and the generation of micro cracks. The amount of < 150 μm produced in the HPGR grinding stage was twice as high compared with what cone crushing would have produced.

Variations in HPGR product particle size distribution also lead to side effects in other areas of plant performance. Due to the higher fines content the angle of repose was enhanced by 6%. Consequently the capacity of stockyards and material handling systems was increased as well. The particle shape after HPGR is somewhat more irregular compared with cone crusher products. This should be considered when designing the screen in a HPGR circuit to ensure sufficient screening efficiency and to avoid excessive moisture carry over in the oversize of wet screening applications. The influence of feed moisture content on HPGR operation will be discussed in more detail in subsequent paragraphs.

**1.1.4 Disagglomeration**

HPGR’s can effectively be used in place of tertiary crushers for preparing a suitable ball mill feed. This can be accomplished either by operating the HPGR in open circuit, in closed circuit with edge recirculation, or by operating in closed circuit with dry or wet screening. Each circuit configuration has its own benefits and drawbacks [Van der Meer et al., 2008]. Due to the high pressure applied by HPGR the material is partially discharged as a compacted agglomerates (called flakes or cake) which may fall apart easily, but also may require further desagglomeration. When a screening circuit is considered the proportion and strength of the flakes will influence the screening efficiency and circulating load.

The strength of flakes is ore-specific, and is also influenced by e.g. feed moisture, clay content and operating pressure. To be able to evaluate flake strength and predict desagglomeration requirements, flake strength tests and desagglomeration tests were developed by Humboldt

Wedag in conjunction with the Los Colorados project. At present, these tests are standard procedure included in pilot test programs at Humboldt Wedag’s laboratories. At Los Colorados the decision was made to install two desagglomerators to ensure high dry screening efficiency since testing had shown compact flakes. However, with changes in ore type and increasingly dry feed material the flakes became more brittle and were observed to fall apart readily upon material transfer and dry screening. The desagglomerators were thus decommissioned.

With the operating experience from Los Colorados the standard flake test and its relation to plant data was greatly improved. When CMP installed another HPGR for their El Romeral Plant utilizing the same circuit layout as Los Colorados, standard flake tests were carried out and the results suggested that a mild desagglomeration step would be required. With the advice of Humboldt Wedag the client designed a belt transfer point, consisting of a tower with internal baffle plates, to break the flakes and ensure in this simple way sufficient screening efficiency (Figure 6).

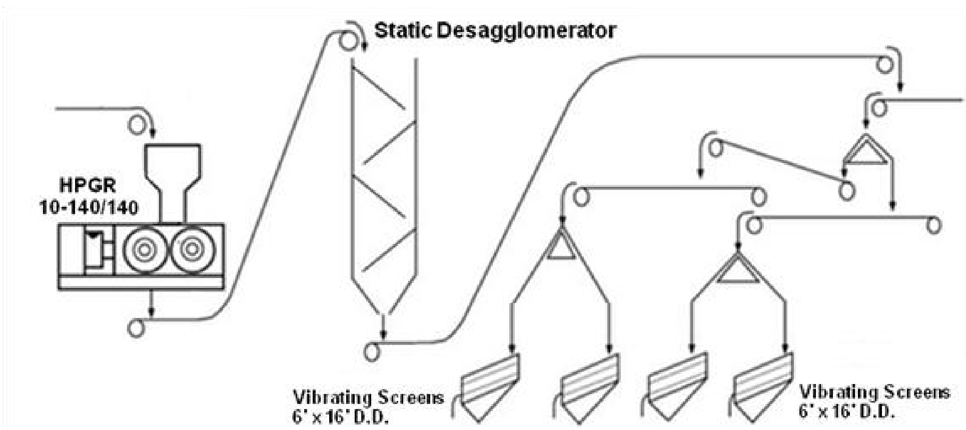


Figure 6: Desagglomeration at Romeral

When (wet) screening is used in the HPGR circuit the issue of flake strength may become more severe. Flakes or flake fragments may survive breakage during transport, and a large proportion may also survive the screening stage unbroken, thus significantly reducing screening efficiency and contributing to an increased circulating load. Moreover, when oversize material from wet screening is recycled back to the HPGR, the contribution to higher moisture content in the HPGR feed may lead to difficulties in material flow in and out of the HPGR feed bins, extrusion during compression, and generally may contribute to a deteriorating performance of the HPGR. Testing for flake competency and moisture effects thus is of importance and these findings should be takeninto consideration when designing the (wet) screening circuit.

**2.0 VASILKOVKA OPERATION GOLD ORE**

The Vasilkovsky region is one of world's largest gold fields and the site of the largest gold deposit in Central Asia. It is located in Akmola Oblast in north-eastern Kazakhstan and has been producing gold for more than 30 years. Vasilkov Gold JV (Vasgold GOK) is developing this deposit, which has an estimated total gold reserve in excess of 400 tonnes, and is an operating company under the umbrella of KazZinc. KazZinc is a major producer of copper, precious metals, zinc and lead, with some 21,000 people in mining, ore dressing, metallurgy, power generation and mechanical production. The company was established in 1997 through the merger of Eastern Kazakhstan's three main non-ferrous metals companies.

Vasgold has recently commissioned a new mine and processing plant, for a capacity of about 9 Million tonnes of ore per year. The new $700-million processing plant will allow KazZinc to increase output by between 6 tonnes and 8 tonnes this year and between 13 tonnes and 15 tonnes in 2011. The Vasilkovka plant treats a complex ore, where the gold is included as free gold, as inclusions to and in sulphide minerals, and as refractory gold. The plant incorporates a complex flow sheet including gravity separation, fine grinding, and a number of new technologies, such as Leachox intensive leaching [1], stirred mills for ultrafine grinding, and HPGR as the third crushing stage, ahead of ball milling.

High Pressure Grinding Rolls (HPGRs) proved to be attractive as final crushing stage due to their large unit capacity (design over 1,400 t/h per unit), fine crushing performance, low specific energy [2], and additional advantages in gold liberation. The present application of HPGRs at VasGold is to provide a final crushing stage and increase ball mill throughput by providing a mill feed at a reduced grindability and a high fines content, as a feasible alternative to SABC circuits **[8]**.

**2.1 Operating Experience at Vasilkovka**

Steered by the above performance indicators, KHD Humboldt Wedag was contracted for the supply of two HPGR units RPS 16-170/180 for the tertiary crushing stage. The units are operating in parallel, in closed circuit with a partial product recirculation. The machines each process 1,500 t/h (HPGR effective feed rate), generating a product of 80 % < 5 mm from a 40-50 mm top size feed (Table 2).

Table 2: HPGR data of Vasilkovka

| **HPGR model:** | | **RP 16-170/180** | |
|---|---|---|---|
| Roll type: | Shrink-fit Tyres | Feed size: | 0-50 mm |
| Roll surface: | Stud lining | Product size: | 80 % < 5.0 mm |
| Roll width: | 1,800 mm | Feed moisture: | 2-5% |
| Roll diameter: | 1,700 mm | Specific energy: | 1.5-2.1 kWh/t |
| Feed material: | Coarse gold ore | Motor size: | 2 x 1750 kW |
| HPGR throughput rate: | Up to 1,500 t/h | Ball mill Wi before HPGR: | 16.5 kWh/t |

The circuit does involve recirculation of a part of the HPGR discharge, at a recirculation ratio of up to 180 % (recycled material in proportion of fresh feed).

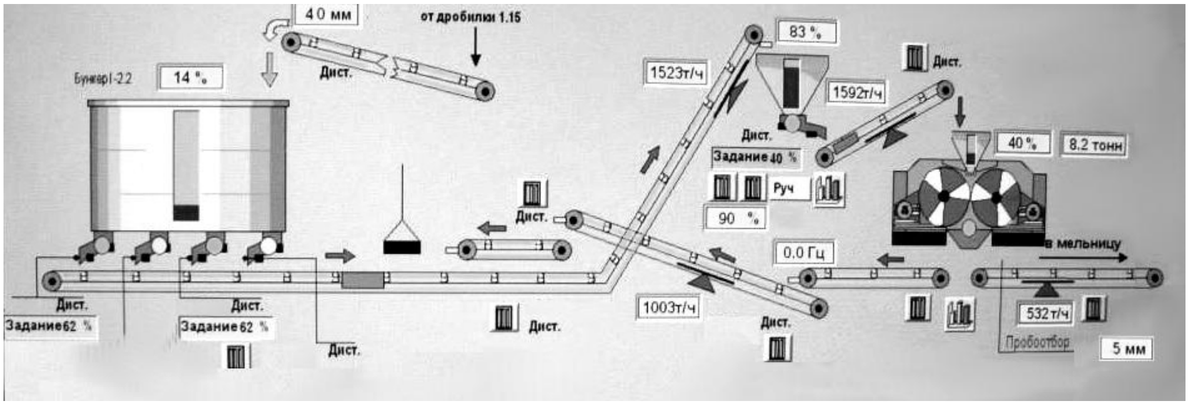


Figure 7: Simplified flow sheet of HPGR based on the Vasilkovka control panel display

**2.2 Circuit Design with Partial Product Recycle**

Depending on the application, a variety of arrangements can be and are applied for HPGR circuits. This is a result of the inherent process of HPGR grinding, where the size reduction takes place in a particle bed, as disintegration of ore particles through inter-particle crushing in the created bed between the rolls. In contrast, conventional crushers rely on single particle breakage for their size reduction, as a contact crushing between grinding media (rods, balls, jaw crusher or cone compartment surface). Thus, in HPGR crushing the particle to be crushed can be, and preferably should be, of a dimension smaller than the applied operating gap.

One direct effect is that the crushed particles can be led to recycle through the same HPGR unit, either directly, or after classification, or after intermediate beneficiation. In conventional crushing, this would require a subsequent separate crushing stage in a unit or in multiple units with a smaller gap setting (tertiary and quaternary crushers), or rod mills. In an HPGR unit, a fresh feed with a top size of, for instance, 40 mm could be combined with a recycle stream of crushed material of near 5 mm from a product recycle arrangement without classification, and still be subjected to a very effective grinding at an operating gap of about 35 mm [3]. This does save in additional screening facilities, and still allows for a fine feed suitable for subsequent ball milling.

At Vasilkovka, the latter approach is successfully applied. This is achieved by installing a product splitter following the HPGR, allowing for a partitioning of the product material. The edge material (the relatively coarse material generated at the left and right shoulders of the rolls; Figure 8) and a portion of the centre material are split-out by mechanical cutters, and returned to the HPGR feed conveyor for re-crushing. This recycle mass also adds in evening-out any feed fluctuations The centre portion from the rolls discharge, which contains the finer and more compressed material, is cut out by the splitter and forms the final HPGR product. Obviously, a different arrangement (such as splitting the full HPGR discharge stream after mixing of the centre and edge material) could be applied as well.

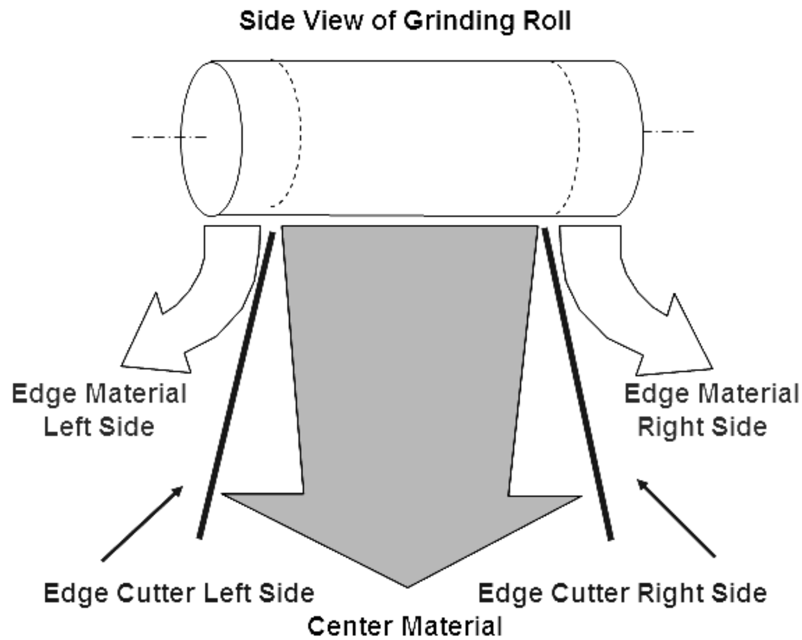


Figure 8. Product Splitter Principle

The application of a product splitter arrangement is a feasible arrangement, but relies to a large extend on a strict control of the feed rate to the roller press. At Vasilkovka the filling of the pre-bin, to provide choke feed conditions, was warranted by an adequate arrangement of a steady and uninterrupted feed supply from the intermediate feed bin by installation of variable speed vibratory feeders and a short variable speed conveyor belt. It was recognised that no short reaction control could be applied to the return flow of (approximately 912 t/h) of splitter product, and that the major control available comes from control of the (ca.530 t/h) crushed feed supply. The belt conveyor from the intermediate bin has a relatively short retention time (< 10 seconds), which thus does allow for an adequate control and response time over the filling level of the pre-bin.

### 2.2.1 Flakes

One of the phenomena that take place during HPGR compression is that compacted material is present in the HPGR product. This compacted material, also referred to as "flakes", is generated by a the high compressing force on the bed of particles in the rolls ʻ gap, causing part of the ground product to discharge in the form of cake-like briquettes (Figure 9).

Figure 9. Examples of Flakes from Vasilkovka Material Test Work

Thus the HPGR product often is composed of a mixture of loose product and a proportion of flakes and flake fragments, the latter ranging from 0 % to 80 % by volume, depending on ore, particle size, moisture content, and pressing conditions. For Vasilkovka, the proportion of flakes in the centre product was modest; some 10-20 % by volume (Figure 10). Also the flakes proved to be relatively brittle, and partly fell apart on handling and transfer (on belt conveyors, transfer points and bins).

Figure 10. Flakes in the HPGR Discharge at Vasilkovka

A series of standard tests for flake competency were carried out during confirmation testing. These flake competency tests are based on the disintegration of flakes in a tumbling mill, and returns a so called "Tumbling Factor" on a scale of 0 % to 100 %, in which 0 % represents very hard flakes, and 100 % indicates total disintegration of the flakes. The presently generated flakes scored near 70 %. As the downstream process does not include classification, but only product splitting, with the final product being directed to the ball mill (sump), it is seen that the flakes at the indicated strength do not pose any problems and no desagglomeration stage is required to assure optimum product handling. The flake material disintegrates almost instantly when entering the mill or a pump sump ahead of a hydrocyclone cluster. This was one more reason to apply a product recycle arrangement for Vasilkovka, as desagglomeration ahead of an eventual screening did show or was shown to be a less attractive alternative.

**2.3 Wear Life**

As with the Los Colorados unit, wear measurements are taken periodically during the life of a set of tyres. Figure 3 shows the typical wear profile for one of the rolls after operation of 10 Months. This illustrates the progress of wear of surface expressed in millimetre of depth over the width of the roll. A total of 58 positions were measured, on 4 locations over the rolls" circumference (at 0°, 90°, 180°, and 270°). The measurements indicate a low wear over 10 months of operation, in a pattern that is specific for the VasGold coarse ore operation (Figure 11). The end of the useful life for the rolls in the above example would be reached at about 30 mm wear, still some 10-12 months away at the time of measurement.

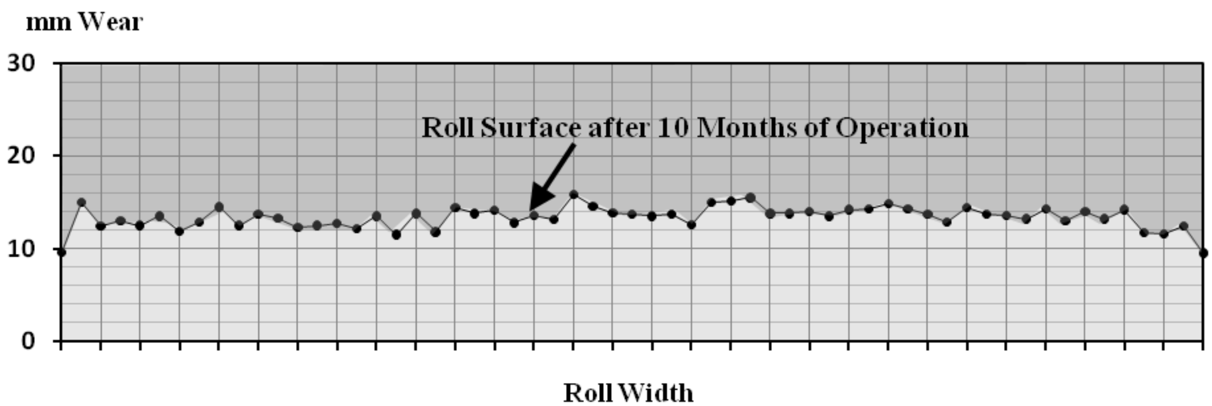


Figure 11: Typical wear profile of coarse ore operations

The shoulders of the rolls were wearing slower. This lower wear leads to the rolls edges standing higher on the surface. These would need to be ground-off to avoid the roll surfaces touching each other at the edges, and to maintain an optimum rolls operating gap. In future roll sets, the rolls' edges will be designed with a softer stud quality, to avoid the above uneven wear. Measures such as described above lead to an increase in wear life at VasGold, which today is expected to increase to about 12,000 hours.

**2.4 Feed Presentation and Segregation**

Especially in cases where a significant circulating load is maintained, but basically in all cases where coarse ores are processed, a strong emphasis and attention must be given to a proper lay-out in the feed system upstream of the HPGR. An ill-designed bin and conveyor system may rapidly lead to feed size segregation on conveyor belts and in bins. In such a case, arranging the feed belt discharge lengthwise to the rolls axis promotes particle size segregation in the HGPR feed bin. Size segregation in the feed bin invariably results in improper material particle size distribution across the width of the rolls, such as coarse feed on one side and fine feed on the other. At most crusher types (cone crushers, impact crushers) or ball mills this is of a much less significance, but for HPGRs this may lead to an uneven wear of the roll surface, an impaired size reduction, and roll skewing.

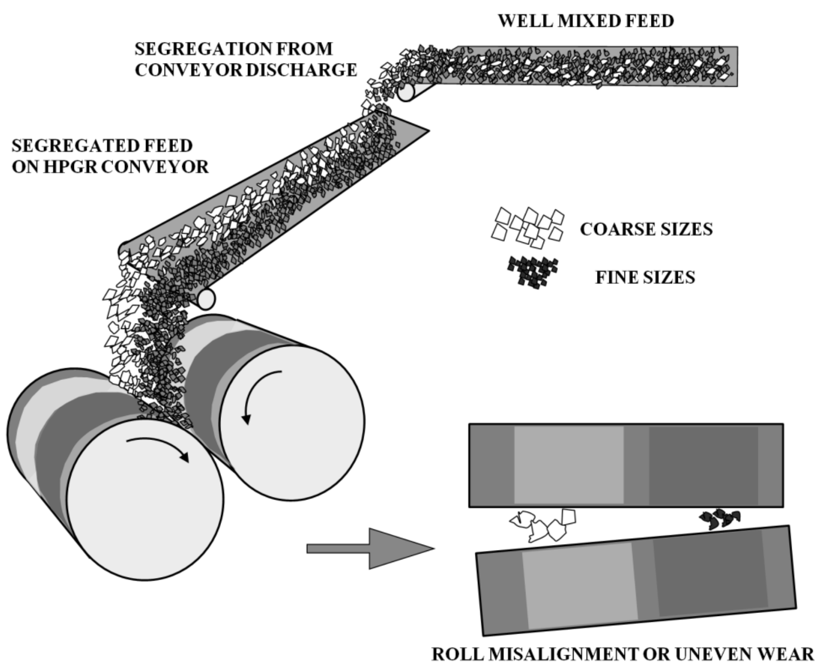


Figure 12. Schematic Sketch of Feed Size Segregation

As example of a condition where a pronounced particle size segregation was present (Figure 12), a particle size analyses for the right side of the a conveyor belt indicated 40 % > 20 mm, with 30 % < 5 mm, whereas the left side did show a much finer composition of only 10 % > 20 mm, with 50 % < 5 mm (Figure 13).

Figure 13. Feed Size Segregation on a conveyor belt.

Such feed segregation does result in uneven process conditions and roll skewing (a condition where the rolls are not parallel to each other, but form a wedged gap opening across the rolls width). Although an automated control system is in place to correct temporary skewing, a structural feed segregation does generate a difference in operating pressure, material packing and gap opening over the rolls ‘ width. These lead to an operation away from the specifications, with a coarser product (from lower than required specific pressure and a wider operating gap), a lower throughput, and an irregular operation. Moreover, aggravated by uneven nipping conditions, an uneven static pressure from the feed chute above, and relatively high particle mobility, an uneven local wear does result, leading to a significant reduction in operating life of the rolls surface and thus higher operating cost.

At Vasilkovka, the feed system includes four vibratory feeders from the holding bunkers, and a recycle of the splitter product from the HPGR discharge, loaded on top of the layer of feed mass on the conveyor. A careful alignment of the throw of the four feeders was taken care of, and a system to ensure an even distribution of the returned fines over the fresh feed was designed to avoid segregation of coarse and fine material. The filling of the HPGR feed chute was arranged perpendicular to the rolls ‘ axis. Additional baffle plates may be built into the feed bin to enhance proper mixing.

Plant operators have reported that especially at low feed rate conditions (at maintained roll speed), at low feed bin levels, an in-balanced feed supply and distribution over the rolls did occur, promoting a skewed situation, leading to material bypass or coarse material from incomplete compression grinding. A smaller than desired operating gap did imply a very low effective pressure, and a low grinding efficiency. Figure 14 shows the KHD hydraulic system designed to control roll skewing and distribution of the forces equally on the cylindrical roller bearings.

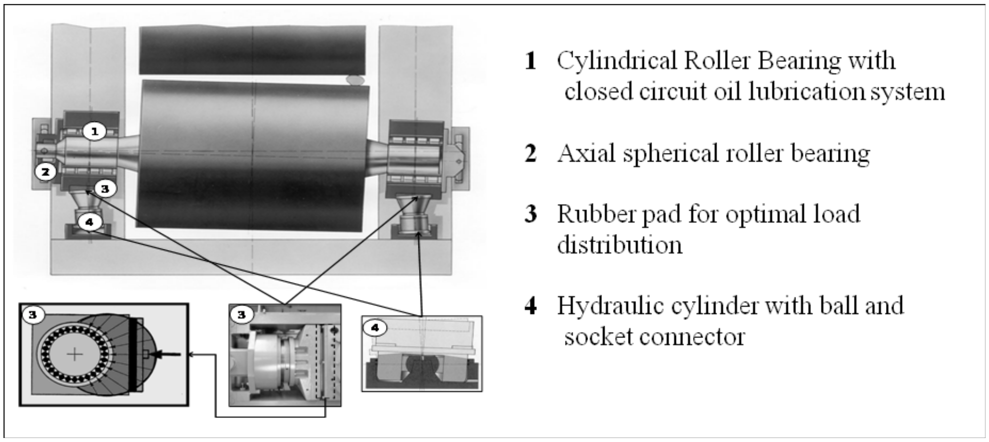


Figure 14: Roller support system in a skewed condition

One of the main functions of the KHD control system is to maintain a parallel gap, especially in the more difficult to grind coarse and hard rock applications [5, 6].

## 3.0 NURKAZGAN OPERATION IN COPPER ORE

At the Nurkazgan copper plant of Kazachmyss, Kazakhstan, two HPGR units are operating in closed circuit with product recycle. The units effectively perform the duties of tertiary and quaternary crushing stages, and were commissioned at the end of 2007 (Figure 15).
The units have a capacity of 850-950 t/h, at a product recycle of approximately 75 % - 125 % (effective recycle mass in proportion to fresh feed) for an initial feed top size of 35 mm. Ultimate product size is down to 80 % < 0.8 mm, with up to 60 % < 74 µm, at a specific power consumption of 1.8 to 2.2 kWh/t. Anticipated roll wear life for Humboldt Wedag´s Stud-Plus® tyres is 8,000 operating hours.

Table 3: HPGR data of Nurkazgan

| **HPGR model:** | **RP 13-170/140** | | First Stage |
|---|---|---|---|
| Roll type: | Shrink-fit Tyres | Feed size: | 0-30 mm |
| Roll surface: | Stud lining | Product size: | 80 % < 5.0 mm |
| Roll width: | 1,400 mm | Feed moisture: | 3-5 % |
| Roll diameter: | 1,700 mm | Specific energy: | 1.2-2.0 kWh/t |
| Feed material: | Coarse copper ore | Motor size: | 2 x 1150 kW |
| HPGR throughput rate: | Up to 1,000 t/h | Ball mill Wi before HPGR: | 16.5 kWh/t |

| **HPGR model:** | | **RP 13-170/140** | Second Stage |
|---|---|---|---|
| Roll type: | Shrink-fit Tyres | Feed size: | 0-10 mm |
| Roll surface: | Stud lining | Product size: | 80 % < 1.0 mm |
| Roll width: | 1,400 mm | Feed moisture: | 4-6 % |
| Roll diameter: | 1,700 mm | Specific energy: | 1.2-2.2 kWh/t |
| Feed material: | Coarse copper ore | Motor size: | 2 x 1750 kW |
| HPGR throughput rate: | Up to 900 t/h | Ball mill Wi before HPGR: | 16.5 kWh/t |

The HPGR centre product is led over a scalping screen to break-up any large agglomerates, and is subsequently classified by hydrocyclones to remove the finished product at about 95 % < 0.2 mm for flotation. The hydrocyclone overflow is further ground in the primary ball mill (figure 15).

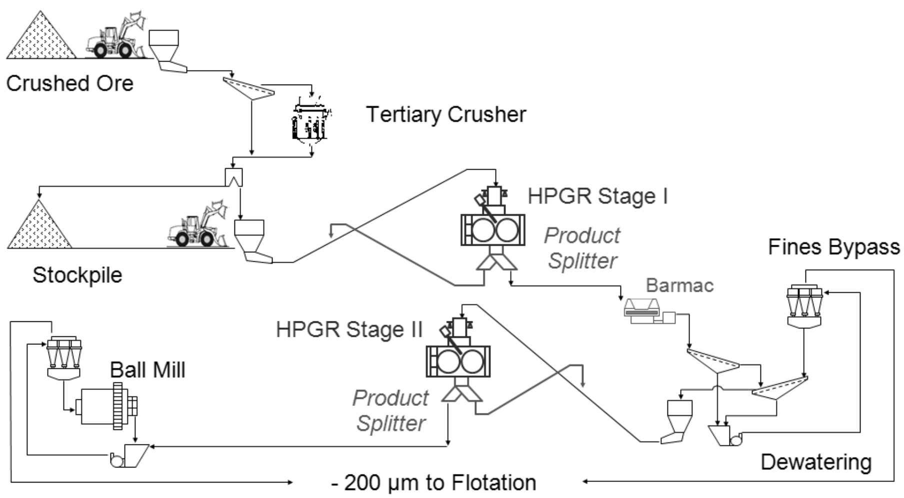


Figure 15: Nurkazgan Grinding Circuit Flow Sheet

The high proportion of fines in the HPGR central discharge fractions, which stems from the high circulating load over the product splitters, allows a significant proportion of the ore to bypass the primary ball mill. In addition, the HPGR pre-ground product does reflect a lower ball mill work index, and the energy input in ball milling is reduced.

At the time of this writing, a further evaluation of the process and effects of HPGR grinding for the copper plant is being carried out. Where benefits from a high reduction ratio and low energy input achieved by the HPGR units are being recognised, the operation of the two-staged circuit is being reconsidered. Especially the effect of desagglomeration and wet screening after the first HPGR are subjects of study. Desagglomeration of the compressed copper ore is a requirement for effective and efficient screening at the 5 mm aperture employed. For this, the initial scrubber was replaced by an impact crusher, to avoid introduction of high moisture content in the screen overflow returning to the second HPGR. This high moisture content was recognised as cause for a less than optimum performance of the second stage HPGR. As an intermediate solution, Nurkazgan selected to run the HPGR circuit as a single stage operation, with both a partial product recycle and a product screening as was, at 5 mm aperture. The screen oversize is re-directed to blend-in with the fresh feed, thus keeping the moisture content of the effective HPGR feed within controllable and acceptable boundaries.

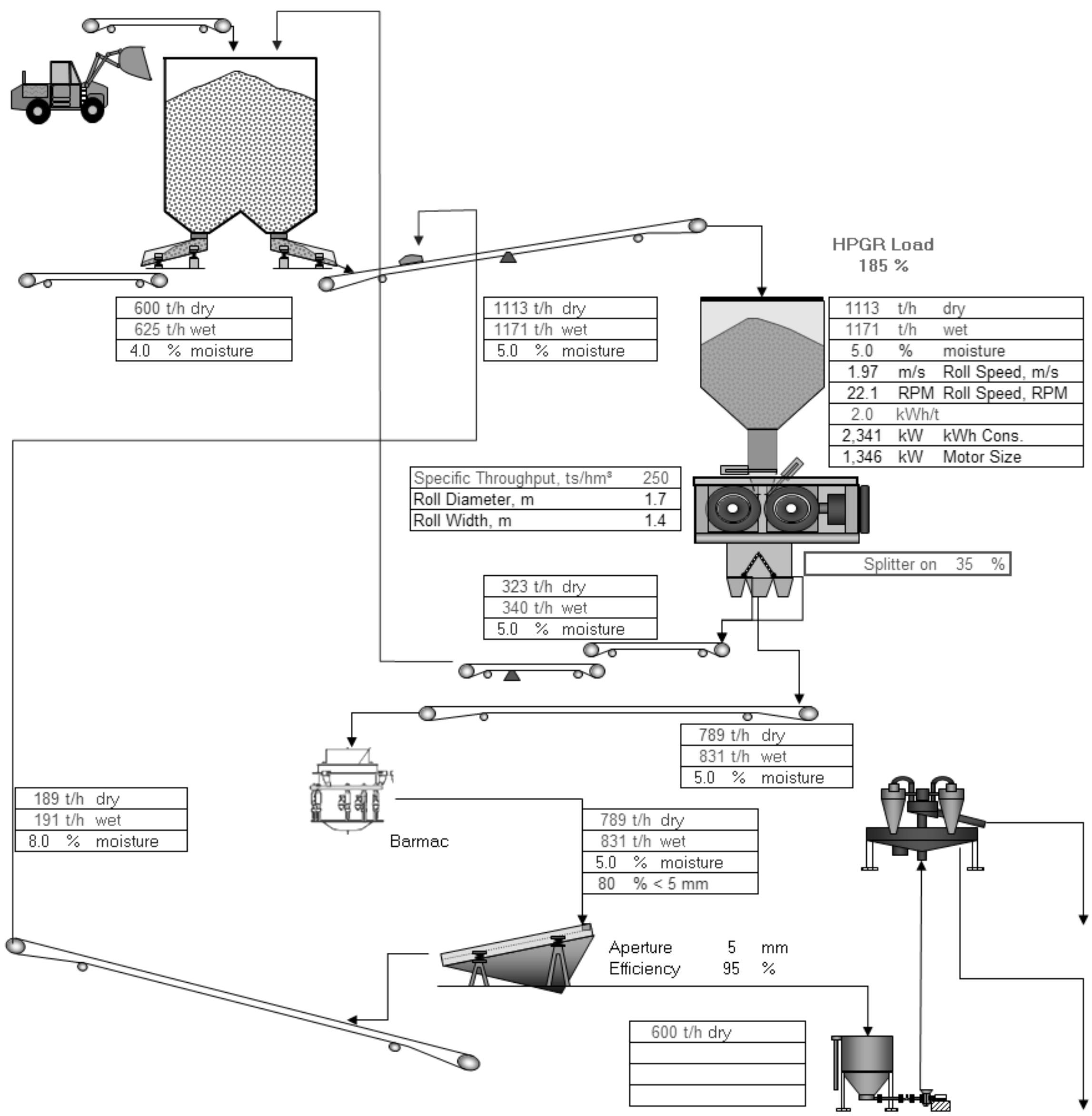


Figure 16: Nurkazgan Revised Primary HPGR Flow Sheet

## 4.0 TRUNCATED FEED

In some instances, a proportion of fines can be removed from the final (HPGR) crushing stage feed by screening, in an attempt to bypass the stage with already finished material, such as feed for the subsequent ball milling, or to avoid a further size reduction and ultra-fines generation from fines already present in the feed.

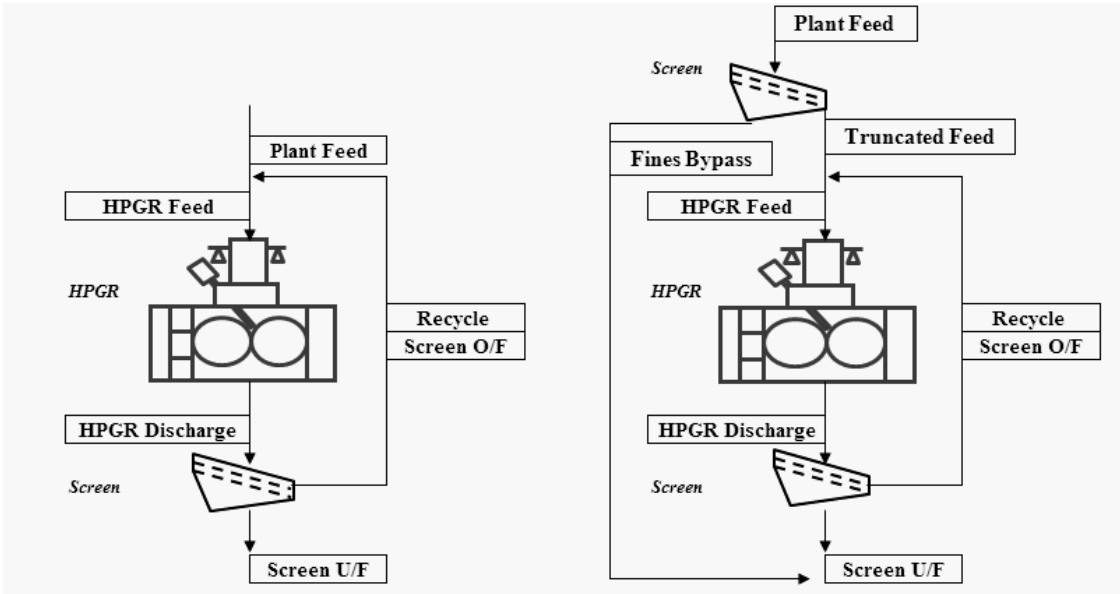


Figure 17: Full Feed versus Truncated Feed Flow Sheet

Depending on the initial fines content in the feed, the product particle size for a truncated feed in many cases is relatively similar (though slightly coarser) to that from a full feed crushing. This does imply that the size reduction from a truncated feed might be more efficient, with a higher net fine product generation.

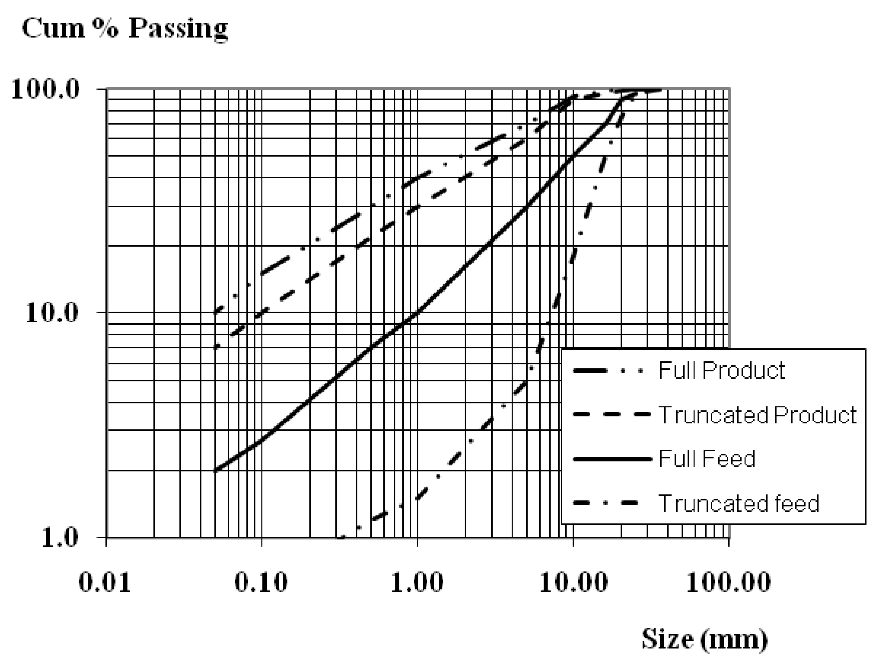


Figure 18: Full Feed versus Truncated Feed Size Distributions

This so called truncated feed however also generally results in a strongly reduced specific throughput, as a lower bulk density and fewer fines to fill the void space in-between the ore grains resulted in a decrease in specific throughput. There is a relationship between the screen size used to prepare the feed and the specific throughput of the HPGR, where the HPGR specific throughput drops by up to e.g. 35-40 % with increasing screen size (the top size of the fines removed). This relationship is illustrated inFigure 19.

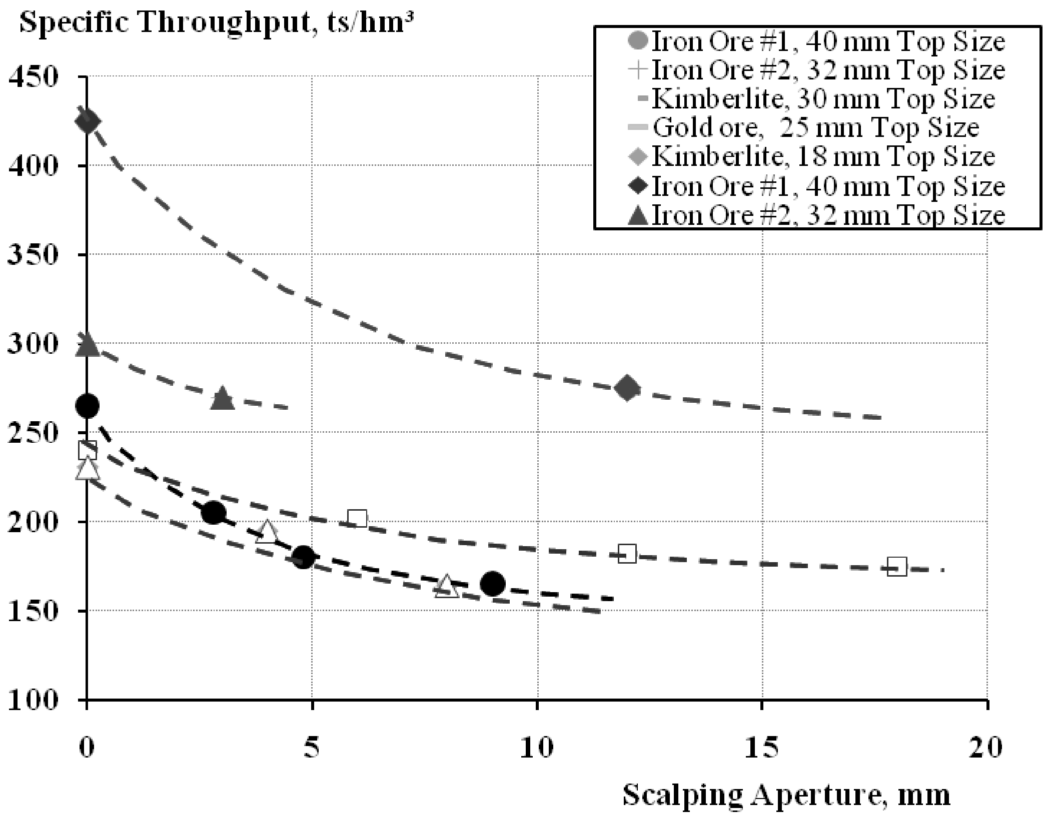


Figure 19: Specific Throughput as a function of Truncated Feed Bottom Size

As the quantity of fines removed from the HPGR feed increases, the apparent trends in performance are that the specific throughput of the HPGR drops due to the increase in void space in the HPGR feed with a resultant reduction in the operating gap. The efficiency of the grinding increases, in terms of fine particle production. In some cases, the overall HPGR product may become finer and energy consumption increases with increasing specific energy input and with a finer pre-HPGR screen size.

The shifting balance in a lower mass flow to the HPGR may in some cases result in smaller equipment size, even though a lower specific throughput is achieved, but may also generate a more complex plant lay-out, with more conveying and screening. The balance of possible advantages (smaller equipment, less ultra-fines) and disadvantages (higher wear, more recycle and screening) must however be evaluated for each plant design and ore situation.

As a consequence of the lower specific throughput, from a similar applied press force and overall energy consumption, the net specific energy consumption generally increases, in some instances by up to 50 %. In an overall assessment, the reduced plant and equipment size sought for by bypassing the fines is not seldom overruled by the reduction in specific throughput and increase in net specific energy consumption. These effects often result in similar required HPGR dimensions and therefore to compensate the lower specific throughput, the rolls sometimes have to be operated at a higher peripheral speed, which would increase roll surface wear. In addition, a

truncated feed does generally generate a less strong "autogenous wear layer", where the relatively coarse fragments do tend to break-away the coating on the roll surface. This also increases the roll surface wear rate. Thus operating cost (from a more frequent replacement of worn grinding rolls) may increase for a truncated feed. Overall, the balance for justification of a truncated circuit is mainly determined by effects of a truncated feed on the reduction of mass flow to the HPGR (proportion of fines in the HPGR section feed), the added surrounding arrangements in conveying and screening, the reduced specific throughput and increase in specific energy, and the anticipated increase in roll surface wear rate.

## 5.0 CONCLUSIONS

Installation and commissioning of HPGRs in coarse iron ore, gold and copper processing plants was concluded successfully, with the 1.7 m diameter KHD Humboldt Wedag HPGR units performing well on specification. The HPGR product recycle arrangement provides a means for size reduction of the feed material without requirement of a screening facility.

The operations confirmed the moisture content of the feed to be a critical controlling variable. Maintaining this moisture at a well defined range does ensure an effective size reduction, as well as steady operating conditions, low wear from an effective autogenous coating of the KHD stud-lined rolls, and minimizing difficulties in material transport and hold-up in bins, feed chute and on conveyor belts.

Feed segregation was identified as another important issue to address. A well designed feed circuit does provide for a well tuned HPGR feed without significant segregation. In combination with a well controlled hydraulic pressure and roll positioning system this allows the units to operate with an optimized gap control and parallel roll surface setting.

The quick exchange facility of the "SWING" frame of the HPGR does allow for a fast rolls exchange procedure, minimizing downtime to below 24 hours and requiring a minimum of installed auxiliary maintenance facilities.

Justification of a truncated circuit is dependent on the effects of a truncated feed on the reduction of mass flow to the HPGR (proportion of fines in the HPGR section feed), the added surrounding arrangements in conveying and screening, the reduced specific throughput and increase in specific energy, and the anticipated increase in roll surface wear rate.

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