CONSIDERATIONS FOR MULTISTAGE HPGR GRINDING IN IRON ORE PROCESSING

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ABSTRACT

High Pressure Grinding Rolls (“HPGR”) are applied in all stages of iron ore size reduction, from coarse ore grinding down to pellet feed preparation. In closed circuit operation, fine grinds can be achieved using HPGR in combination with dry or wet classification or a partial product recycle without classification. For fine product cuts, this generally implies the necessity of accepting a high circulating load, with consequential material handling issues and larger equipment sizes and capacities. It has been suggested that using multiple HPGR passes ahead of classification would generate a higher proportion of product size fractions to the classification stages, thereby reducing the volume of recycled oversize and leading to an overall more economic processing. In this publication, some of the issues associated with multiple pass HPGR arrangement are discussed.

KEYWORDS: HPGR; multi-pass; iron ore; pellet feed; classification; process efficiency.

RESUMO

Moagem de Alta Pressão Rolls ("HPGR") é aplicável a todas as fases da redução de tamanho de minério de ferro desde a fase de britagem terciária até a moagem fina como a preparação para a pellet feed. Na operação de circuito fechado, a moagem fina pode ser obtida com a utilização do HPGR em combinação com classificação a seco ou úmido, ou com uma recirculação parcial do produto sem classificação. Para cortes de produtos finos, isso geralmente implica a necessidade de aceitar uma carga de circulação elevada, desta forma, há necessidade de manuseio de materiais e consequentemente a necessidade de utilização de equipamentos com maiores capacidades. Tem sido sugerido que o uso do HPGR em múltiplas passagens na fase anterior a classificação geraria uma proporção maior do produto nas frações de tamanho ideal para a fase de classificação, reduzindo assim, o volume do material a ser reciclado, e consequentemente, conduzindo a um processamento mais econômico. Nesta publicação alguns dos problemas associados ao arranjo da instalação do HPGR com múltiplas passagens são discutidos.

1. INTRODUCTION

HPGR does allow significant savings in operating cost for especially harder ores, and is presently used in a wide variety of operations using either open circuit (single pass) or closed circuit arrangements with classification. One of the benefits, besides low energy consumption and a high unit throughput, is the ability to generate a product containing a high proportion of fines. Especially in closed circuit with classification this facilitates a high overall reduction ratio and a very attractive preparation of feed for downstream further grinding and / or beneficiation [van der Meer et al. 2009]. For fine products however, this generally implies accepting a high circulating load, with consequential material handling issues and larger equipment sizes and capacities.

Recognizing the high fines generation, the option presents itself for generating even more fines using the HPGR mechanism. Where the application of a higher pressure can be used to get some extra fines, the additional specific energy required for such higher pressure may not always provide the best economical answer. An alternative approach could be found in using a multi-stage concept, whereby re-passing the HPGR discharge through successive next stages of HPGR could be applied. This would generate a higher proportion of product size fractions to the final classification stages, result in a reduction of the volume of recycled oversize and could lead to an overall more economic processing [Liu&Luo 2010].

Such an approach might apply to both fine HPGR grinding in wet or dry circuits, or in pellet feed generation. In closed circuit operation, fine grinds can be achieved using HPGR in combination with dry or wet classification or a partial product recycle without classification.

Several issues play a role here, such as moisture content, the general requirement for large equipment size, materials for providing adequate wear resistance, and circuit footprint.

2. MULTIPASS GRINDING IN A SCREENING OPERATION

The application of a dual (or more) HPGR arrangement will generate a product with a significant higher proportion of fines. When operating in a system including wet or dry screening classification this could be expected to generate a significantly lower recycle, due to a lower proportion of screen oversize being returned to the HPGRs.

The feed to the screens would contain less coarse material and more fines. Considering that a similar mass flow of fines has to be treated, the screen area required to cope with the throughput would be similar or even lower. Of course this depends on issues such as the respective screening parameters, the material transport behavior of the screen feed and effective screen efficiency performance.

For example, considering a plant 4000 t/h with a feed size distribution of 80 % < 40 mm, a single HPGR could generate a discharge product of 80 % < 13 mm and 50 % < 3 mm. A second HPGR pass could then further reduce the material to a product of 80 % < 8 mm and 67 % < 3 mm (Table 1, Figure 1).

Table 1. Example of HPGR Product Sizes for Single and Double Pass Operation.

Size	Feed	HPGR Discharge 1st Pass	HPGR Discharge 2nd Pass
mm	cum.% passing	cum.% passing	cum.% passing
47.3	100	100	100
33.6	69	99	100
16.8	31	85	92
12.0	24	79	87
8.4	17	69	82
3.0	7	47	67
0.8	2	31	48
0.3	1	23	38

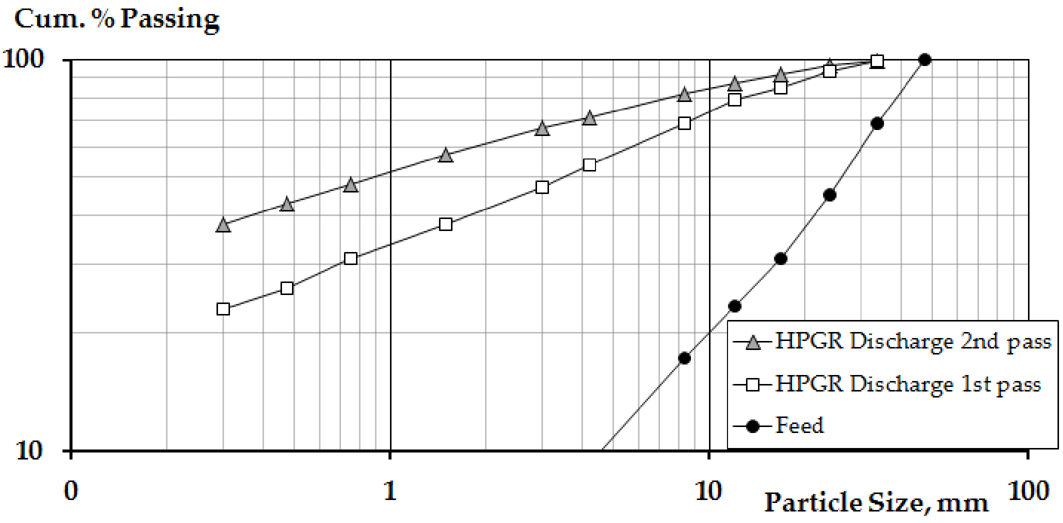

Figure 1. Example of HPGR Product Sizes for Single and Double Pass Operation.

Depending on the screening efficiency, the recycle load for a 3 mm cut size would reduce from about 220 % (HPGR feed in proportion to fresh feed) in the single pass HPGR situation to about 150 % for the double pass option.

An example calculation of required screen surface area can be done [Nichols, 1982] for a 3 mm screening for the screen feed sizes of 47 % < 3 mm, 38 % < 1.5 mm for the single HPGR pass or 67 % < 3 mm, 57 % < 1.5 mm for the double HPGR pass. This does suggest that the screen surface area for the double pass conditions for the same screen feed rate reduces to 86 % of that of the single pass situation. When calculated on the basis of a same screen undersize mass flow, the required screen surface area reduces even further, to about 61 % of that of the single pass situation.

The overall cost savings of such an arrangement must be balanced against a higher capital and operating cost of more HPGR units installed (e.g. two smaller units instead of one bigger unit), and the material transfer facilities between the HPGRs. However, capital and operating cost savings could be expected for the conveying and screening. In this, operating a number of HPGR in series (i.e. multi-pass operation) could increase the size reduction achieved over single-pass operation for the same cumulative specific energy input [Norgate & Weller 1994].

Thus depending on the balance of CAPEX and OPEX for the respective HPGR, materials handling and classification stages, cost savings could be expected for a multiple pass HPGR system with screening.

3. MULTIPASS GRINDING IN A DRY PROCESSING ARRANGEMENT

Dry screening is generally suitable down to about 5 mm, and wet screening to finer size ranges. For very fine products (< 1 mm), however, screening may become less attractive as a large screening surface area and a large number of units would be required to effectively perform the task. For fine product applications, where the material is dry or where the subsequent process is carried out dry, air classification presents a viable alternative to wet classification. It provides a means to generate products from a top size range of 0.1 – 5.0 mm by static classifiers down to a very fine pellet feed size range of 20-150 microns by dynamic classifiers.

Dry classification was developed in conjunction with the HPGR technology for cement processing, as a further development from the classical dry gas cyclone facilities. Presently, these systems may consist of static (cross-flow) separators for a mid-range classification (80-1,500 µm), followed by dynamic (cage wheel) separators for a finer range of products (25-150 µm) [Strasser 2010, Van Der Meer 2011].

The cross flow separator acts by passing an air flow across a stream of falling particles in-between a cascading track of louvre plates, thereby blowing the fines out of the falling stream. The dust is swiftly taken out of the process, and only coarse, nearly dust-free material requires conveying. The fines are collected through a dust cyclone and bag house system, or directed to a dynamic classifier stage. Grinding plants world-wide are installed with such cross flow separators, mostly as a first (rougher) classification stage, and operate virtually maintenance-free.

A dynamic air separator is generally applied as a finishing stage in dry classifier arrangements, following the cross flow separator stage. In the dynamic separator a flow of air or gas, laden with the fine particles, is blown through a vertically or horizontally spinning cage wheel. The coarser particles or middlings particles in the bulk are thrown back by impact or friction with the vane blades and are recovered from a bottom-discharge valve, whilst the fine dust passes through the slots to be collected in a gas cyclone and bag house dust collection system.

Presently, a large number of cement operations are applying the above unit processes to generate either a finished product or a pre-ground product for subsequent ball milling [Strasser 2008, 2010; Binner 2006]. In these installations, a HPGR is combined with one or both of the above classifiers.

A typical layout for such a grinding plant is shown in Figure 2, with the classifiers placed separate from the HPGR. Rejected coarse material from the static separator and dynamic classifier is transported back to be combined with the HPGR feed.

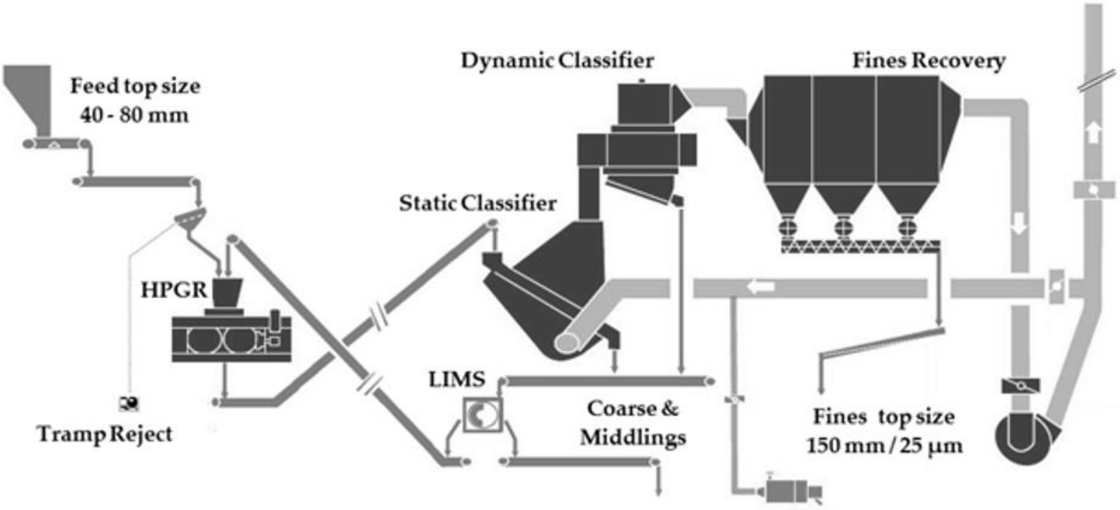

Figure 2. Lay-Out Example of Design for a “GrindX” Dry Iron Ore Grinding Plant.

Only the relatively coarse, dust-free discharge of the cross flow separator thus requires transport. A latest design cross flow separator of a flatter shape enables a lower overall height of construction.

When operating in a system of dry air classification (and possibly magnetic separation), the application of a dual (or more) HPGR arrangement may lead to a higher proportion of fine product generated, and thus to a significantly lower recycle. Overall, less or smaller equipment could be required for material handling and smaller HPGRs can be applied.

An example of product size distributions for a magnetite iron ore material is given in the Table 2 and Figure 3.

Table 2. Example of HPGR and Air Classifier Product Size Distributions for a Magnetite Ore.

Size	Feed	Single Pass	Two Pass		Fines
mm		HPGR Discharge	HPGR I Discharge	HPGR II Discharge	
	cum.% passing	cum.% passing	cum.% passing	cum.% passing	cum.% passing
50.0	100	100.0	100.0	100.0	
22.4	84.9	99.2	93.3	96.9	
11.2	62.3	92.3	83.2	91.6	
5.60	41.5	76.5	67.4	79.6	
1.00	12.9	36.3	33.1	50.7	
0.315	4.7	17.2	13.5	29.6	100.0
0.125	2.6	11.9	8.8	20.0	74.1
0.071	2.0	9.2	7.3	16.9	62.6
0.045	1.6	7.7	6.6	15.0	55.5
0.020	1.2	6.5	5.7	12.4	45.9

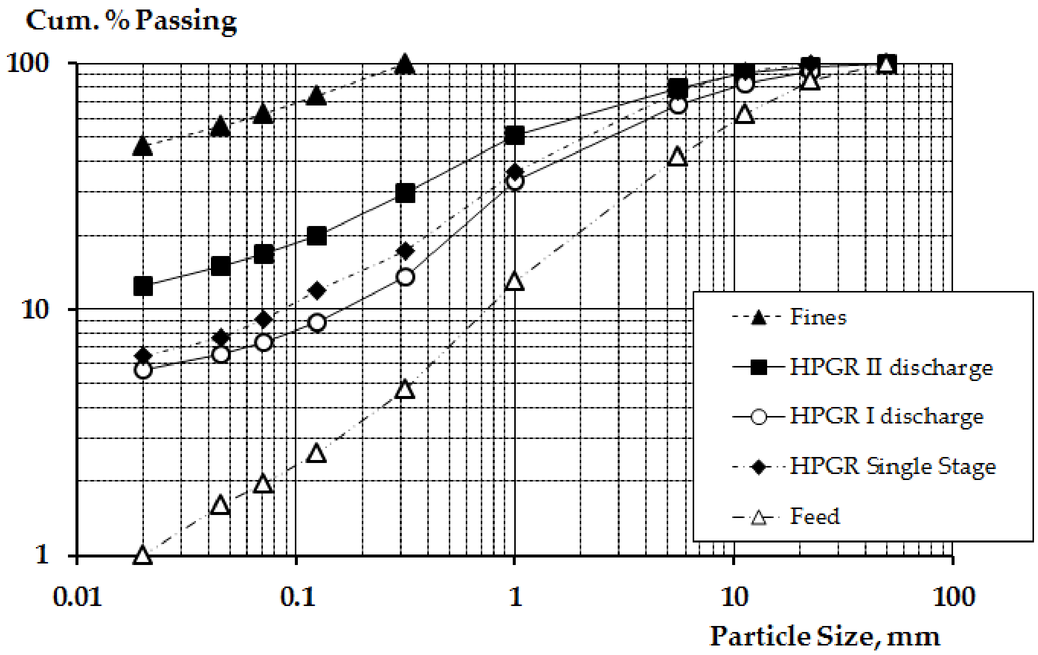

Figure 3. Example of HPGR and Air Classifier Product Size Distributions for a Magnetite Ore.

In this example, a classifier fines were assumed as a product of < 300 microns with a fineness of near 80 % < 150 µm, from a HPGR discharge of 80 % < 6-10 mm.

Simulations and calculations were carried out to assess the effects of applying a double pass HPGR as compared to a single pass HPGR in such an air classification arrangement. The results for a two-pass operation are summarized in Figure 4 for a double pass circuit. In this, it was assumed that a magnetic separation would be able to reject 15 % of the classifier middlings as low iron content non-magnetic tailings.

The mass balances calculated did indicate that the circulating load for a double pass circuit would reduce by some 40 %, from 595 % to 345 % (HPGR and classifier feed in proportion of fresh feed) as compared to a single pass operation.

As in the case of screening, the benefits of having two (smaller) HPGRs in series instead of a single bigger one would partly come from a smaller conveyor system and a smaller static classifier section, which reflects on both CAPEX and OPEX. In the air classification the limiting factor could be the final (dynamic) classification stage. Irrespective of how the preceding circuit is arranged, a similar mass flow of fines has to be treated. Given an assumed air loading, the dynamic classification and subsequent fines handling system (gas cyclones, bag house or precipitators) would not greatly differ in size or operating cost.

The main savings in operating cost would come from smaller HPGR equipment, operating at a lower pressure level as compared to a single large unit, an easing on the coarse (static) classifier side, and significantly lower material handling facilities.

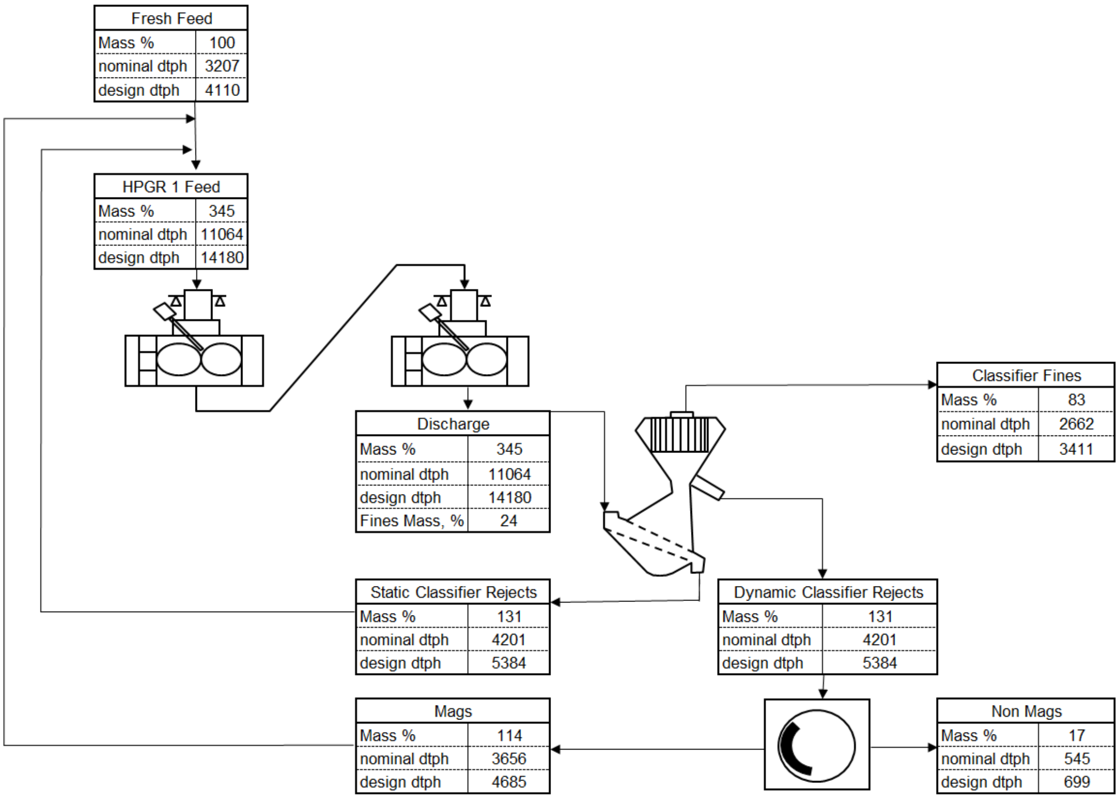

Figure 4. Mass Balance of HPGR/Air Classifier circuit with a double pass HPGR.

4. MULTIPASS GRINDING IN PELLET FEED PROCESSING

In iron ore pellet feed preparation conventional processing involves ball milling, sedimentation, thickening and filtration. In recent years, HPGR units were introduced either as pre-grinding stage or as finishing stage after ball milling to improve the Blaine specific surface area of the final product. In this scheme, an alternative arrangement consisting of a multi-pass HPGR process may provide a simpler flow sheet with lower operating cost, reducing the energy consumption as compared to ball milling and avoiding the necessity of sedimentation, thickening and filtration.

Such a flow sheet incorporating a consecutive multi-stage HPGR arrangement could be schematically indicated as in Figure 5.

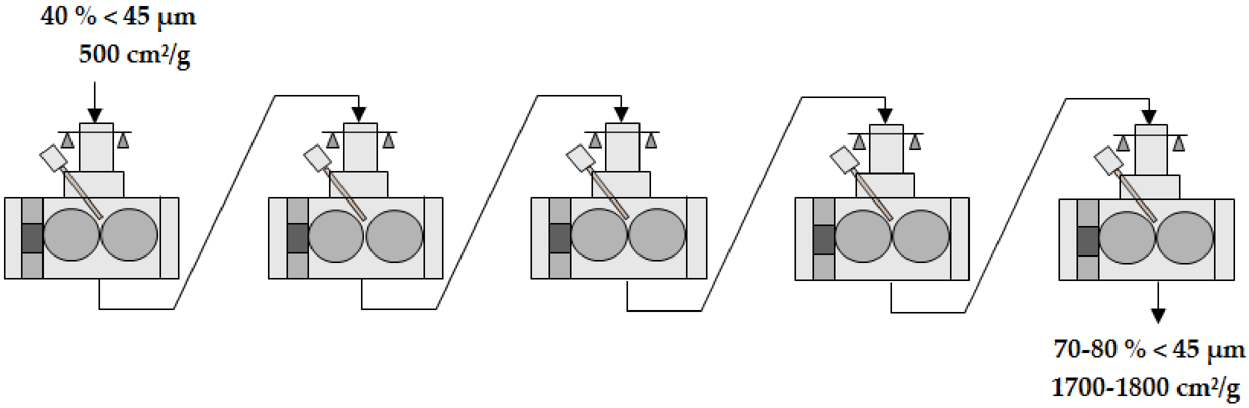

Figure 5. Schematic Summary of Multi-Stage Grinding Approach.

An evaluation was carried out for assessing the merits of such a system for pellet feed grinding, considering an aimed product quality with a specific surface area near 1700-1800 cm²/g. Starting point could be a feed of 100 % < 250 µm, with about 40 % < 45 µm, with a Blaine specific surface area of about 500 cm²/g.

Various HPGR pilot test series were run to test the concept. The HPGR had a stud-lined roll surface and rolls with a diameter of 0.80 m and a width of 0.25 m. Table 3 summarizes the test conditions and results of a series with a specific pressure of 4.0 N/mm², a roll speed of 18 RPM and a feed moisture level of 8%.

Table 3. Summary of HPGR Multi-pass Test Conditions and Results.

HPGR Pass	1	2	3	4	5
Specific Pressure, N/mm²	3.9	3.9	3.9	3.8	3.3
Operating Gap, mm	6.7	5.6	4.3	3.6	3.3
Specific Throughput, ts/hm³	179	224	195	178	165
Specific Energy, kWh/t	1.9	2.3	2.8	2.9	3.0
Blaine Specific Surface Area, Centre, cm²/g	1047	1539	1682	1734	1745
Blaine Specific Surface Area, Feed, cm²/g	511	881	1274	1487	1576
Incremental Blaine Surface Area, cm²/g	536	547	199	69	26

Apart from the starting run, the specific throughput showed to decrease in each pass, from 224 ts/m³h at the second cycle to 165 ts/m³h after five passes through the HPGR, more or less in line with the decreasing operating gap. The net specific energy consumption increased with progressing passes, from 1.9 kWh/t in the first pass to 3.0 kWh/t in the last pass. The Blaine specific surface area increased with the number of passes, but the incremental change decreased markedly. The final 5th pass did show a Blaine value of 1745 cm²/g in the center material, at a particle size distribution of 79 % passing 44 µm.

For the conditions applied, the pressure built-up on the material bed between the rolls could only be reached in the first cycles; after that the pressure resistance of the material reduced. Depending on the feed moisture and other conditions, the achieved operating pressure reduced by up to 50 % as compared to the aimed pressure level. Concurrently the operating gap reduced to close to the zero gap setting of the rolls. This dependency of performance on material compression resistance is seen in various applications and is a basic phenomenon in high pressure material compaction [van der Meer & Dicke 2008].

With the progress of the number of passes, the net specific energy consumption increased and the specific throughput first increased (due to a lower bulk density at start and a higher bulk density of the compacted product from the first pass), and then decreased. Where in coarser ore applications the size reduction efficiency reduces [Hilden&Suthers 2010], the effect in the fine and wet pellet feed appears to stem more from a reduced pressure resistance of the material mass with an increasing proportion of fines. Thus the operating gap reduced, which is directly reflected in the specific throughput, and the energy input was consumed by a smaller mass flow, thus showing a higher specific energy consumption.

The Blaine specific surface area increased with the number of passes (Figure 6), but at a digressive pace.

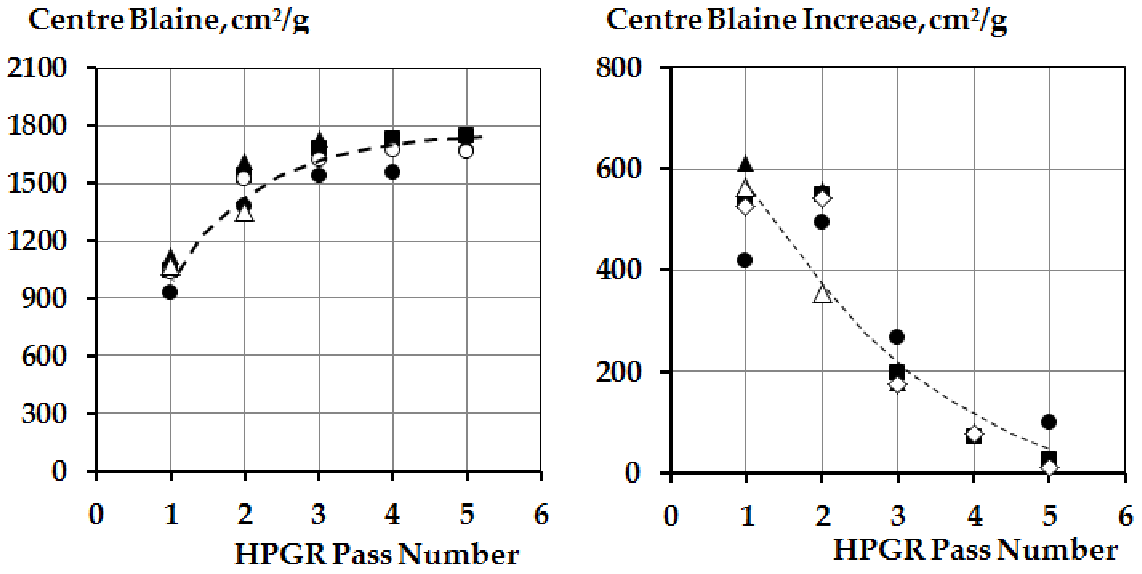

Figure 6. Example of Progress of Blaine Specific Surface Area and Incremental Blaine with increasing number of HPGR passes.

Apparently the relationship between Blaine value of the HPGR product and HPGR feed was relatively flat (Figure 7), and the increase in Blaine value of the product did display a decreasing trend as a function of Blaine value of the feed. In other words, the higher the Blaine in the feed and the more HPGR stages were applied, the smaller was the incremental gain in Blaine specific surface area.

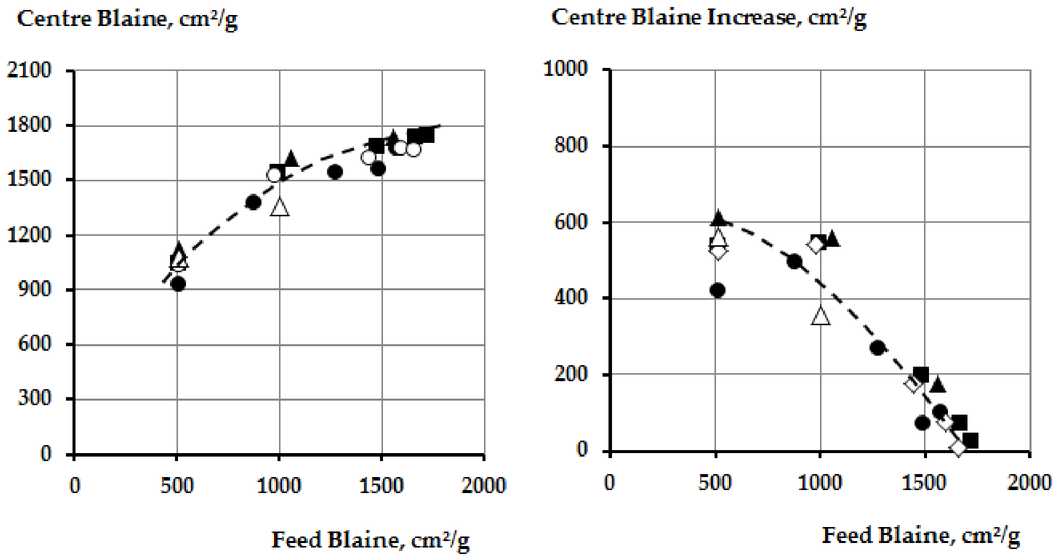

Figure 7. Example of relationship between Blaine Specific Surface Area of Feed and Product, and between Blaine Specific Surface Area of Feed and Incremental Blaine.

So a multiple pass grinding for iron ore pellet feed results in a progress in fineness and specific surface area of the product, but does so following a digressive trend. The finer the feed to the HPGR, the more energy input appears to be required, and the lower is the specific throughput. In sizing the HPGRs, this needs to be taken into consideration: operating parameters such as roll speed and operating gap for each stage HPGR will differ.

Considering the sequential chain of HPGR units, process fluctuations will be passed-on from one HPGR to another. An off-balance in one HPGR will require a controlled response form the following or preceding HPGR. This may lead to fluctuations in process conditions such as roll speed and operating pressure. It is anticipated that the dynamic behavior of the circuit as a whole requires a dedicated control philosophy and possibly a surge bin requirement between HPGRs. It is assumed that a well-defined (master-slave) control structure should be in place to maintain HPGR process conditions and associated mass flow within strict performance boundaries.

The HPGR discharge product generally does partly constitute of a proportion of compressed material flakes, which have a thickness approximately equal to the operating gap, and are up to some 35 mm across the surface. These flakes do in most cases allow a relatively trouble-free transport through standard conveyor and feed chute arrangements. They are relatively soft and easily compressed in subsequent HPGR stages. Only when very wet the flakes become a rubbery texture, and will tend to coagulate, whilst sticking to surfaces and promote bridging in chutes.

5. CLOSING REMARKS

HPGR can be considered a versatile size reduction technology for a wide variety of iron ore processing flow sheets for the generation of a wide range of product size fractions. HPGR circuits and equipment are considered as proven and robust technology in the iron ore and other minerals processing systems. As multiple pass arrangement of several HPGRs in series, in combination with product recycling or classification, potential savings could be identified in the anticipated size and operating cost of classification and materials handling equipment.

The overall cost savings of such an arrangement must be balanced against a higher cost of more HPGR units installed (more smaller units versus one bigger unit), and associated material transfer facilities between the HPGRs on one hand and capital and operating cost savings for the conveying and classification on the other hand. In this, the potential of operating smaller HPGRs at a lower pressure level (and energy consumption) as compared to a single larger HPGR should be taken into account.

In pellet feed applications capital and operating cost savings could be expected for a multiple pass HPGR system as compared to a conventional route of ball milling, sedimentation, thickening and filtration. Depending on the application and feed regime, evaluation of operational stability and the eventual application of inter-stage hold-up bins would be recommended.

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