INCREASED MASS RECOVERY FROM DESLIMING AT VARGEM GRANDE 2 USING THE NEW MODEL CAVEX® 2 (CVD) HYDROCYCLONE*

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Abstract
The new Cavex® 2 (CVD) hydrocyclone was proposed to optimize the desliming stage performance at Vargem Grande 2 Plant (VGR2), located in the Iron Quadrangle, where the average iron ore slimes losses correspond to approximately 18% by weight of the total iron ore mined, totaling 1.9 million tons of iron lost every year. To further explore the desliming performance of the Cavex® 2 (CVD) cyclones compared to the original Cavex® (CVX) one applied to low-grade itabirite ores, the effects of the apex and vortex were examined by combining static simulation and industrial tests. Results showed that the combination of the LIG+(TM) inlet and new chamber design in the CVD hydrocyclone reduces pulp turbulence and promotes an increased volumetric capacity of approximately 30%. Furthermore, the new hydrocyclone presents a finer granulometric cut for the same cyclone diameter and apex/vortex configurations when compared to CVX, in addition to the greater mass separation to the underflow and consequent 9 p.p gain in mass recovery. Finally, adjustments to the geometric configurations of CVX cyclones were not enough to achieve the same separation performance as CVD, with the latter model achieving the best separation efficiency with approximately 6 p.p improvement.
Keywords: Cavex® 2; Desliming; Hydrocyclone; Iron Ore.

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1 INTRODUCTION

Limitation and rapid depletion of high-grade iron ore reserves is a major and growing concern in the minerals industry, which mainly stems from the rise in worldwide steel demand [1]. For this reason, the importance of low-grade iron ore processing, which has a large amount of gangue components [2], has increased significantly [3]. As the liberation degree decreases, a higher level of fine grinding is required in beneficiation plants to ensure sufficient ore release or product suitability [4], resulting in greater amounts of ultrafine particles, also known as slimes.

The processing of low-grade itabirite ores through reverse flotation of quartz can be challenging, mainly in the presence of so-called slimes, considered smaller than 10 µm [5,6], and associated to hydrated minerals. Many [7,8,9,10,11] claim that ultrafine particles in flotation systems result in negative effects on recovery, selectivity, and reagent consumption, which can be attributed to their small mass, higher specific surface, and high surface energy [8]. Since slimes cause significant harmful effects on flotation efficiency, it is usual to remove these particles before this stage [12], which can be observed worldwide, as well as for the itabirite iron ores beneficiation industrial flowsheets in the Iron Quadrangle in the Southeast of Brazil [13], where slimes are removed in hydrocyclones [11].

The removal of iron ore slimes through hydrocyclones was developed by the USBM and registered since the 1940s [14]. A study carried out by Lima, Peres, and Marques [15] with distinct iron ores from the Iron Quadrangle revealed that bypass of fines to the underflow on the desliming hydrocyclones lower than 4% did not cause problem in flotation recovery or the concentrate quality. On the other hand, in practice, there are substantial iron metal losses in the desliming stage in Brazil [16,17,18], India [19,20,21,22,23] and Russia [24]. Matioli [25] and Mukherjee [26] assert the average iron ore slimes losses corresponding to approximately 20% by weight of the total iron ore mined. As a result, slimes are discarded as waste and stored in tailings dams [1] leading to critical environmental impact [27], besides significant value losses. In view of this problem, the Engineering Processing team at Vale searched a new hydrocyclone model to replace the first-generation Cavex® (CVX) hydrocyclone and improve the desliming stage performance at Vargem Grande 2 Plant (VGR2), where approximately 1.9 million tons of iron are lost every year in the desliming overflow, representing 18% of the run of mine (ROM) mass.

For many years, the Weir Group has carried out optimization research, development and trials of the structural form and parameters of hydrocyclones aiming at developing a promising application for ultrafine classification, which has been challenging. As a result, the company firstly introduced in 1996 the original Cavex® CVX hydrocyclone, known for its 360° laminar spiral inlet geometry, which offered a step change in hydrocyclone performance by reducing turbulence within the feed chamber, leading to a sharper classification, lower bypass, and decreased misplacement of coarse particles. Following years of development, Weir improved the hydrocyclone with the creation of LIG+$^{(TM)}$ inlet and new feed chamber design, presented in Figure 1, marking the launch of Cavex® 2 (CVD). This hydrocyclone' s design allows to carefully guide the slurry into the cyclone feed, achieving a stabilized flow pattern and reducing turbulences in the cyclone, which results in up to 30% additional capacity while occupying an equivalent area as the CVX and concurrent hydrocyclones [28]. Given the expected improvements in efficiency and bypass demonstrated by the new CVD hydrocyclone, this equipment was applied to enhance the VGR2 desliming separation performance.

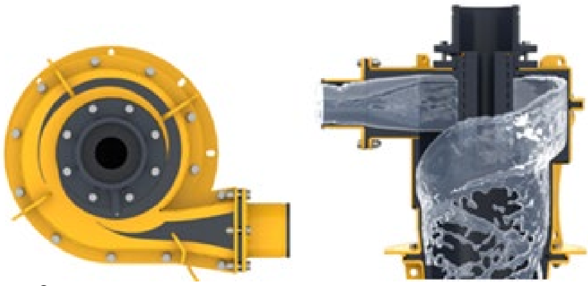

Figure 1 – Cavex® 2 LIG+™ advanced laminar spiral inlet and feed chamber.

The Weir group proposed the CVD hydrocyclone concept, as shown in Figure 2. An industrial trial study was conducted, and the results revealed that compared to CVX, the new hydrocyclone showed advantages in increasing volumetric capacity and underflow mass recovery without impacting flotation quality. To further investigate the desliming performance of the CVD, apex and vortex diameters and separation performance were explored through numerical simulation and experimental tests.

Figure 2 – Cavex® 2 hydrocyclone module.

2 MATERIALS AND METHODS

The Cavex® 2 hydrocyclone was used for separating slimes from the coarse iron ore particles. Its design combines a cylindrical chamber connected to a conical body, leading to the bottom outlet at the apex of the cone. However, in this study, six units of CVD modules, shown in Figure 3, were installed in the VGR2 desliming stage. The retrofitted components comprised a lid and a chamber with dimensions of 888mm x 1054mm x 775mm (width x length x height), with the LIG+$^{(TM)}$ inlet. Further preparation of the modules involved manual coating of surfaces since there were no molds for lining. Both delivery and installation of the component parts of Cavex® 2 at VGR2 beneficiation plant took place in June 2022. Modules were assembled with the existing hydrocyclones installed in the cluster, proving their easy retrofit (Figure 4).

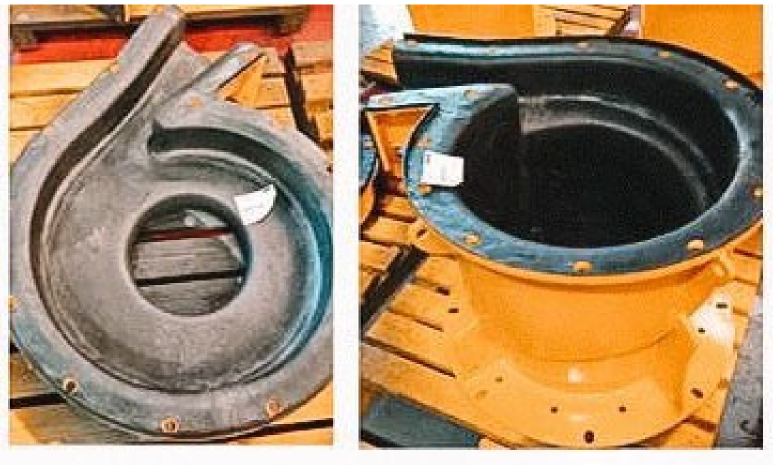

Figure 3 – The lid (left) and the chamber (right) modules.

Figure 4 – Cavex® 2 CVD modules were assembled in situ.

Several comparative industrial tests, in parallel with the former hydrocyclone unit and sampling campaigns, were carried out to evaluate possible improvements using CVD. Samples were characterized using X-ray fluorescence, as well as particle size distribution through gravimetry and wet sieving (0.045mm) followed by laser diffraction, and percentage of solids analysis in feed, underflow, and overflow.

Experimental industrial testing was carried out on CVX and CVD hydrocyclone clusters. During testing, three variables were manipulated: pressure (kgf/cm²), vortex and apex diameters (mm). According to the general recommendation given by Weir, the expected mass recovery improvement could be achieved by using the same diameter for CVD hydrocyclones and larger vortex compared to the original cyclones (170mm). Therefore, tests initially considered a 200mm vortex for CVD and, based on the observed results, supported by Lynch Wills model, vortex diameter was reduced to 170mm, equal to the CVX cyclone (Table 1).

Table 1 – Experimental industrial testing carried out on CVX and CVD clusters.

Test	Date	Battery	Pressure kgf/cm²	Vortex (mm)	Apex (mm)	Solids (%)		
						Feed	Underflow	Overflow
1	07/07/2022	CVD	2.07	200	100	18.6	66.3	11.1
	07/07/2022	CVX	1.96	170	90	18.0	59.9	9.8
2	18/07/2022	CVD	2.09	200	100	17.7	80.0	9.1
	18/07/2022	CVX	1.79	170	90	23.7	56.1	8.9
3	26/07/2022	CVD	1.70	200	100	21.0	74.6	10.2
	26/07/2022	CVX	2.10	170	90	19.6	69.2	9.3
4	09/08/2022	CVD	2.00	185	100	23.1	70.8	13.3
	09/08/2022	CVX	2.10	170	90	22.1	72.4	13.2
5	16/08/2022	CVD	1.90	185	100	29.8	71.7	21.8
	16/08/2022	CVX	2.40	170	90	27.2	68.5	19.9
6	23/08/2022	CVD	2.30	170	100	33.0	75.0	20.3
	23/08/2022	CVX	2.20	170	90	30.4	81.4	21.5
7	30/08/2022	CVD	2.25	170	100	28.0	61.7	14.4
	30/08/2022	CVX	2.30	170	90	28.0	77.8	14.6

Aiming to experimentally study the VGR2 desliming performance using the new CVD hydrocyclone, tests were supported by static processing simulations. The mass flowrate, granulometry, percentage of solids and iron content constituted data input for USIM PAC, used for performing mass balancing, hydrocyclone model calibration and simulating operating conditions, detailed below.

3 RESULTS AND DISCUSSION

Comparative industrial tests performed with CVX and CVD cyclones provided an understanding of the effects of the proposed geometric modifications in Cavex® 2 hydrocyclone on the performance of the desliming system. First, the circuit was adjusted to achieve similar pressures in both cyclone clusters, which allowed to observe the need for fewer operating CVD cyclones, 5 against 7 of CVX, proving the expected volumetric gain of up to 30%. Then, apex and vortex diameters were varied, and recovery and bypass results obtained as shown in Table 2. Notably, larger CVD vortex configurations (tests 1 to 3), compared to CVX, did not present higher recoveries. However, when setting the same vortex diameter for both cyclones, recoveries were considerably higher for CVD (tests 6 and 7).

Table 2 – Experimental industrial results with CVX and CVD cluster.

Test	Date	Battery	Pressure kgf/cm²	Vortex (mm)	Apex (mm)	Underflow Recovery (%)
1	07/07/2022	CVD	2.07	200	100	48
	07/07/2022	CVX	1.96	170	90	55
2	18/07/2022	CVD	2.09	200	100	55
	18/07/2022	CVX	1.79	170	90	74
3	26/07/2022	CVD	1.70	200	100	59
	26/07/2022	CVX	2.10	170	90	61
4	09/08/2022	CVD	2.00	185	100	52
	09/08/2022	CVX	2.10	170	90	49
5	16/08/2022	CVD	1.90	185	100	39
	16/08/2022	CVX	2.40	170	90	38
6	23/08/2022	CVD	2.30	170	100	48
	23/08/2022	CVX	2.20	170	90	39
7	30/08/2022	CVD	2.25	170	100	56
	30/08/2022	CVX	2.30	170	90	47

Given the industrial results obtained, a scenario for the same CVX and CVD cyclone and vortex diameters was considered in USIM PAC, and the partition curves are illustrated in Figure 5. In general, a higher bypass was expected for the new equipment (blue curve) due to the larger apex installed in the new hydrocyclones, 9.4% against 7.0% for CVX. Moreover, smaller d50 delivers the promise of the CVD's improved design to achieve a finer cut, reducing the quantity of misclassified particles to overflow and maximizing mass recovery, as shown in Table 3.

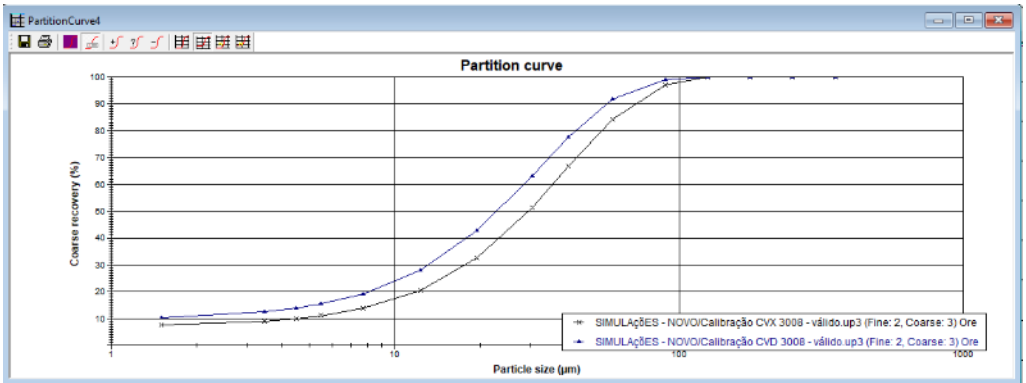

Figure 5 – Comparison of CVX versus CVD partition curves.

Table 3 – Mass recovery for the 1st desliming stage VGR2.

Hydrocyclone cluster	Mass recovery (%)
CVX	47.0
CVD	56.0
CVD gain (p.p.)	9.0

Following simulations increasing the CVX apex to 100mm, corresponding to the CVD cyclone cluster configuration, were performed to evaluate whether adjustments in the geometric configurations of CVX cyclones could bring the same results as those obtained for CVD. The black curve (Figure 6) represents an 11.3% rise in fines bypass, surpassing the one observed for CVD, illustrated by the blue curve. Furthermore, a higher mass recovery to the underflow remained for the CVD hydrocyclone cluster, as seen in Table 4.

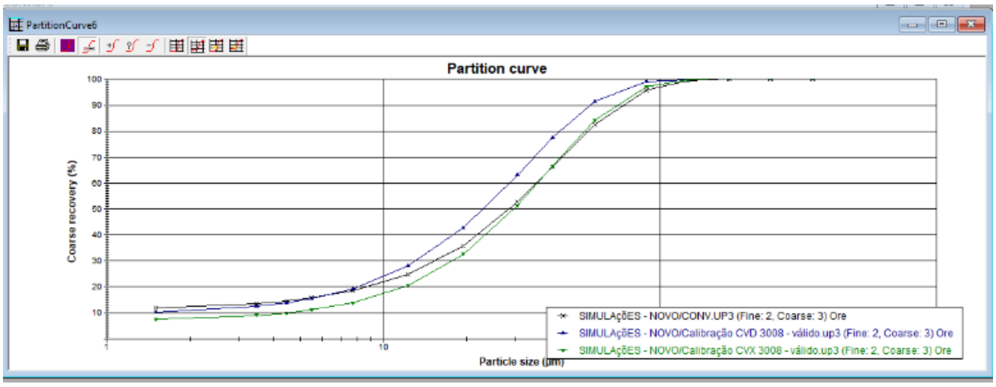

Figure 6 – CVX cyclone battery simulation changing apex to 100mm.

Table 4 – Mass recovery for the 1st desliming stage VGR2, considering a 100mm CVX apex.

Hydrocyclone battery	Mass recovery (%)
CVX 100mm apex	50.3
CVD	56.0
CVD gain (p.p.)	5.7

Another desliming evaluation addressed the fine product generation in the CVX cluster. The simulation calculated the effects of reducing the CVX vortex finder to the diameter installed in the CVD (155mm) as shown in Figure 7. The fine particle bypass (black curve) increased to 9.4%, similar to the one achieved by the new cluster. Vortex reduction decreased d50, but not enough to match the reduction achieved by the CVD cyclone. Hence, again a superior mass recovery was observed for the new generation hydrocyclone (Table 5).

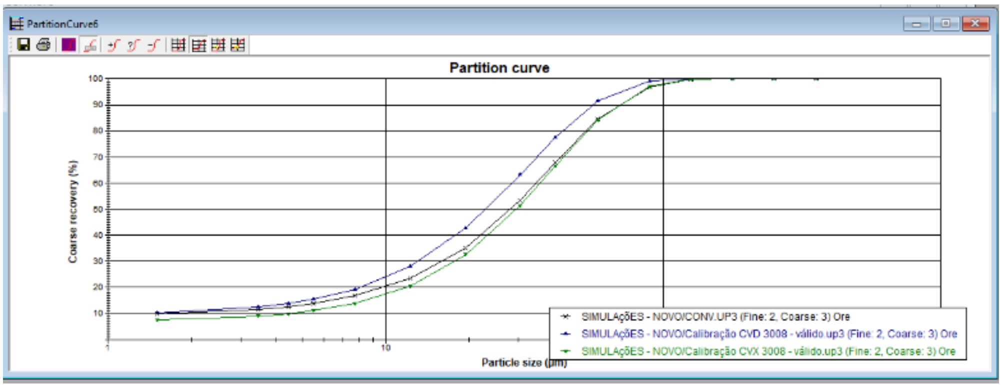

Figure 7 – CVX cyclone cluster simulation changing vortex to 155mm**.**

Table 5 – Mass recovery obtained for the 1st stage VGR2 desliming, considering CVX cluster simulation with 155mm vortex.

Hydrocyclone cluster	Mass recovery (%)
CVX 155mm vortex	50.2
CVD	56.0
CVD gain (p.p.)	5.8

Finally, the simulation of both combined apex and vortex modifications was conducted (Figure 8) showing a superior bypass of fines (14.2%) and a 10p.p. decrease in the percentage of solids directed to the underflow (67.9% of solids for the CVD cluster versus 57.9% simulated for the CVX cyclone cluster with 155mm vortex and 100mm apex), which represents a non-recommended condition for the subsequent operation, the flotation. In this case, a real approximation of the d50 for both curves was observed, but even so this parameter remained lower for the CVD cyclone battery. In terms of underflow partition, a slightly higher mass recovery was still observed for the cluster of the new cyclones, as noticed in Table 6.

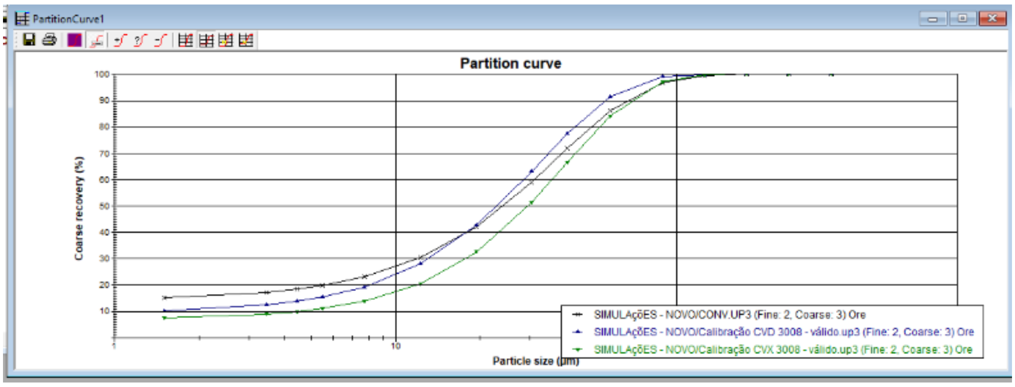

Figure 8 – CVX cyclone cluster simulation changing apex to 100mm and vortex to 155mm.

Table 6 – Mass recovery obtained for the 1st stage VGR2 desliming, considering CVX cluster simulation with 100mm apex and 155mm vortex.

Hydrocyclone cluster	Mass recovery (%)
CVX 100mm apex and 155mm vortex	54.9
CVD	56.0
CVD gain (p.p.)	1.1

In summary, simulations disclosed that apex and vortex adjustments in the CVX hydrocyclones are not sufficient to reach the CVD model's separation performance, 6 p.p. higher. Considering the current desliming cluster conditions at VGR2, Cavex® 2 CVD cyclone achieved the best separation efficiency, improving it by approximately 9 percentage points.

4 CONCLUSION

In this paper, the classifying performance of the Cavex® 2 hydrocyclone compared to the original Cavex® at the VGR2 desliming stage was studied by numerical simulation and experimental tests, and the influence of apex and vortex diameters was discussed.

Considering the same cyclone and vortex diameters for both CVX and CVD, the latter presents a finer granulometric cut, leading to an improvement in mass separation to the underflow by 9 p.p. Increased volumetric capacity up to 30% was also observed, which allows the demobilization of assets. Finally, adjustments to the geometric configurations of CVX cyclones were not enough to achieve the same partition performance as CVD (roughly 6 p.p. higher), proving the latter model's efficiency and transforming this solution into a potential for replication at other Vale's plants.

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