CAVEX® hydrocyclone: a sustainable innovation for transforming mining efficiency

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Abstract. Hydrocyclones have been integral to the mineral processing industry for many years, continuously evolving alongside other technological advancements. Many mining concentrator plants have targeted increased mill circuit throughputs, whereby most hydrocyclones installed in the clusters are operated without standby capacity and with limited space to cater for expanded installation footprints. This paper aims to explain advancements in CAVEX® hydrocyclone technology, highlighting maximising recovery and capacity. Tests were conducted on a customer site using a 400CVXT10 and 400CVDT10 to evaluate comparative efficiency and volumetric flow capacity. All tests were conducted at the same feed process parameters. The results demonstrated an improvement in hydraulic capacity of up to 30% and separation sharpness by >10%. The 400CVDT10 results have been discussed in this paper and compared with the 400CVXT10 in a coal classification application. The main objective of this paper is to investigate the benefits of new CVDT hydrocyclone innovations and their impact on the coal industry.

1 Introduction

A hydrocyclone is a classification device that uses centrifugal force to accelerate the settling of slurry particles and separate them based on size, shape, and density [1]. Hydrocyclones are considered to be attractive for industrial use as they have no moving parts, a small footprint, relatively low capital and operating costs, and are simple to operate. The hydrocyclone is commonly used in mineral processing where it is considered to be highly efficient at fine separations. A hydrocyclone consists of a cylindrical section connected to a conical section. Feed is injected tangentially at high velocity into the upper cylindrical section, creating a strong swirling motion [2]. The swirling motion forms a vortex with a low-pressure zone along the center, where an air core develops, usually connected to the atmosphere through the bottom opening [3]. Separation of the particles occurs based on the relative magnitude of the centrifugal force of the prevailing swirling flow field and the fluid resistance in it [4]. Fine particles are discharged through the overflow pipe, while the remaining suspension containing coarse particles exits through the underflow orifice.

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Design optimisation of hydrocyclone is essential to improve hydrocyclone hydraulic capacity and enhance performance for coal and mineral beneficiation applications.

Scientists have examined the parametric study on the effect of different geometrical parameters with hydrocyclone performance [5]. Recent research has focused on optimising hydrocyclones using computational fluid dynamics (CFD) approach. CFD simulations, employing multiphase models have been used to study flow patterns, pressure drop, and separation efficiency [6]. Findings indicate that reducing inlet dimensions and underflow diameter while increasing overflow diameter can enhance performance. Increasing the depth of the vortex finder improves separation efficiency by extending particle re-entrainment time [7]. Advanced CFD techniques have also provided new insights into air core development and particle separation processes, challenging some traditional views [8]. Although CFD simulations provide detailed insights, industry professionals still rely on semi-empirical models for the scale up and optimisation of industrial cyclones [9]. In recent past researchers have developed semi mechanistic models combining CFD simulations with empirical formulation offers a thorough approach to designing and predicting cyclone performance [10].

Hydrocyclones have also been investigated for coal cleaning, with their efficiency described using Rosin-Rammler and logistic distribution functions [11]. For coals with high near gravity material, a new performance index called Cone Ratio Feed Rate (CRFR) has been proposed to optimise cyclone operation [12].

The dense-medium cyclones (DMCs) have become the primary processing unit in the coal industry. DMCs are widely used in coal beneficiation, with their performance influenced by various design and operational factors [13]. The stability and rheology of dense-medium suspensions significantly impact cyclone performance, with viscosity modifiers enhancing separation efficiency [14]. The dense-medium cyclones (DMCs) have become the primary processing unit in the coal industry. DMCs are widely used in coal beneficiation, with their performance influenced by various design and operational factors [15]. They efficiently separate coal particles, even those with high amounts of near-density material, and allows for precise control of product quality. Control strategies are implemented to ensure the production of high-quality clean coal while also reducing energy consumption. While cyclones can process coal down to fine sizes, they are typically used for particles larger than 0.5 mm [16]. Recent innovations include the CAVEX® dense medium cyclone, which is designed to reduce turbulence and wear at the feed entry point, thereby enhancing separation efficiency [17]. Computational Fluid Dynamics (CFD) simulations have been utilised to analyse and optimise cyclone designs, resulting in new models with better classification efficiency and lower energy consumption [18].

1.1 CAVEX®2 (CVD) hydrocyclone: A new era of efficiency and sustainability

Weir has been a pioneering leader in hydrocyclone manufacturing for over 30 years. The original CAVEX® hydrocyclone (CVX) set new industry standards with its innovative laminar spiral inlet geometry and corner-less 3D curvature, enhancing performance by reducing turbulence and increasing capacity, efficiency, and wear life [19]. In 2020, Weir introduced the high-efficiency CAVEX® 2 hydrocyclone (CVD), their second-generation model. This upgraded hydrocyclone features an advanced LIG+™ laminar and chamber design, which further reduces turbulence and improves classification while maintaining the same footprint as the original CAVEX® and competitor cyclones. Weir's ongoing commitment to research and development ensures that their CAVEX® hydrocyclone range remains at the forefront of the industry (Fig 1).

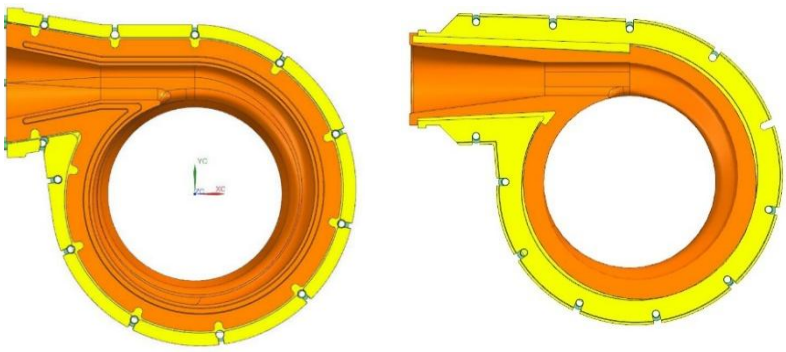

Fig. 1. Innovative inlet design for CAVEX® 2 (left) hydrocyclone versus CAVEX® 1 (right)

Moreover, the water and energy savings of this high-efficiency cyclone reduce its overall cost of ownership and deliver sustainability benefits over the long term. The superior performance of the CAVEX® 2 hydrocyclone is what separates it from the rest. Results from CAVEX® 2 hydrocyclones installed across the globe have shown that it maximises plant recovery by reducing the quantity of misclassified particles; the alpha parameter improves by an average of 10% while the bypass improves by an average of over 15%. Fewer fines are returned to the mill, and mines can reduce their carbon footprint by consuming less energy for small particle reduction.

2 Case study

Weir worked on a project to supply first-generation CAVEX® hydrocyclones for a classification application in a coal beneficiation plant on the request of the customer. Weir cyclone specialists then proceeded to investigate the most effective and sustainable cyclone solution between the first (400CVXT10) and second generation (400CVDT10) CAVEX® hydrocyclones. After evaluating each cyclone selection, the primary objective was to enhance hydraulic capacity and optimise separation efficiency. The potential process and financial implications for the end client were thoroughly examined. The details of 400CVXT10 and 400CVDT10 hydrocyclone design configuration are shown in Table 1.

Table 1. Hydrocyclone design configuration 400CVXT vs 400CVDT

Hydrocyclone Model	**400CVXT10**	**400CVDT10**
Hydrocyclone Dia (m)	0.4	0.4
Inlet (m)	0.11	0.13
Vortex Finder (m)	0.15	0.15 & 0.14
Spigot (m)	0.07	0.07
Cone Angle (deg)	10	10

A series of simulations were performed by the Weir process engineering team to evaluate the performance of 400CVXT10 within the range of specified pressure (55-130 kPa). Similarly, the simulation was computed for the second generation CAVEX® 400CVDT10

cyclone based on the same current feed parameters shown in Table 2 and the same cyclone internals used in the 400CVXT10 simulation.

Table 2. Current cyclone feed process data

Description	Unit
Tonnage (tph)	110
Volumetric Flowrate (m^3/h)	403.3
% Solids w/w	25
Dry Solids SG (t/m^3)	1.5

3 Results and discussion

Various simulation conditions were computed. The results thereof are summarized in Table 3. The first simulation was computed for the first generation CAVEX® 400CVXT10 cyclone based on the current feed parameters shown in Table 1. Similarly, the second simulation was computed for the second generation CAVEX® 400CVDT10 cyclone based on the same current feed parameters shown in Table 1 and the same cyclone internals used in the 400CVXT10 simulation, i.e. a 150mm vortex finder and a 70mm spigot. The cyclone selection using the same internals as the 400CVXT10 cyclone, resulted in a 53kPa pressure which is not within the customer required (55-130kPa) operating range for this specific application. The third simulation was computed for the second generation CAVEX® 400CVDT10 cyclone using the same current feed parameters but a different vortex finder (140 mm) which increased the pressure to 60kPa meeting the customer requirement.

Table 3. Simulation condition with current feed flowrate and increase feed flowrate

	Sim 1	Sim 2	Sim 3	Sim 4	Sim 5	Sim 6
Hydro-cyclone	400CVXT 10	400CVDT 10	400CVDT 10	400CVXT 10	400CVXT 10	400CVDT 10
Flowrate (m^3/hr)	403.3	403.3	403.3	524.3	524.3	524.3
Pressure (kPa)	79	53	60	134	75	101
Vortex Finder (mm)	150	150	140	150	150	140
Spigot (mm)	70	70	70	70	70	70
Quantity	3	3	3	3	4	3

As part of the investigation to assess the performance of both cyclones in terms of feed capacity and to align with the client's future plans for upscaling, the cyclones were selected with a 30% increase in volumetric flowrate, from 403.3 m^3/h to 524.3 m^3/h. Simulation 4 indicates that this increased flowrate resulted in a pressure rise to 134 kPa for the

400CVXT10, which exceeded the client's required range of 55-130 kPa. Consequently, an additional cyclone was necessary to achieve an acceptable pressure of 75 kPa, as demonstrated by Simulation 5. This confirms that the 400CVXT10 could only achieve a flowrate of 131.4 m³/h per cyclone when the flowrate is divided by the number of cyclones per cluster. In contrast, Simulation 6 shows that the 400CVDT10 cyclone could accommodate the increased flowrate with the original three cyclones, thus achieving a 30% increased flowrate of 174.8 m³/h per cyclone. Fig. 3 illustrates the pressure-flowrate capacity curve with two different vortex finders. The innovative inlet and chamber design features of the 400CVDT10 enable the hydrocyclone to classify up to 25-30% more feed slurry while occupying a similar footprint.

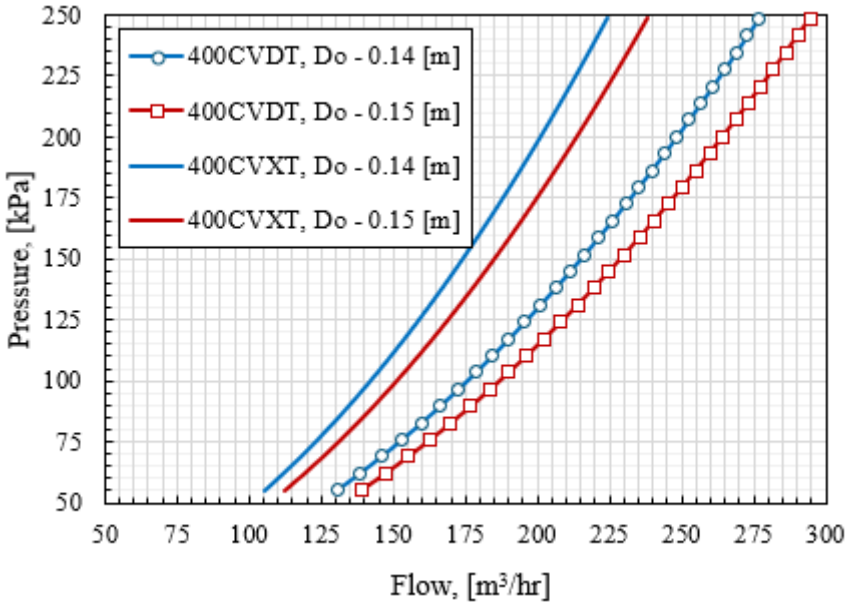

Fig. 2. Capacity flow curve for 400CVDT10 and 400CVXT10

Simulation 4 shows that the increase in volumetric flowrate, three 400CVXT10 cyclones require an increase in operating pressure of 134kPa. This exceeds the accepted operating pressure range (55-130kPa) for the application. This occurs even using the largest cyclone internals i.e., inlet size and vortex and spigot configuration. Should the client need to increase capacity, an additional 400CVXT10 cyclone would need to be installed. Simulation 5 provides a proof of this as an acceptable 75kPa pressure is achieved. In contrast to this, Simulation 6 highlights the capability of the 400CVDT10 to accommodate the increased flow comfortably at a pressure of 101kPa, whilst still achieving an acceptable P80 cut point of 116µm. The separation efficiency is best illustrated with a graph showing the percentage of solids reporting to the underflow against particle size, known as a Tromp Curve or Efficiency Curve. Fig. 3 represents the efficiency curve which is a function of the cumulative % passing each sieve size in the particle size distribution with respect to efficiency. The d_{50}, also known as the “cut point”, is a common metric for distinguishing between fine and coarse solids. Another way to measure separation in a cyclone is by looking at the proportion of fines that goes to the underflow compared to the feed, known as the "*bypass*". The fine sized particles just flow with water and consequently, a fraction of those particles reported to underflow equal to water recovery (R_f) at underflow [20]. This is a common observation in hydrocyclone practice. From Fig. 3, it appears that the 400CVDT10 significantly improve the classification

performance by minimizing the fine bypass (<10%) in comparison to 400CVXT10 hydrocyclone.

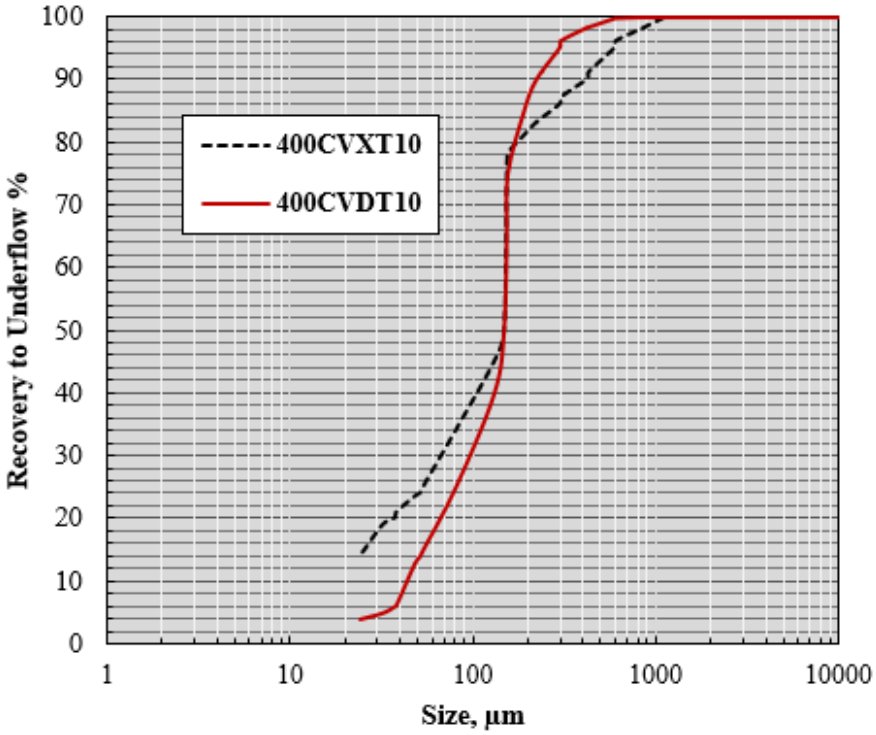

Fig. 3. Partition curve for 400CVDT10 and 400CVXT10

The sharpness of the curve was analysed, and the sharpness index (I) was calculated to confirm the efficiency of particle separation within the cyclone. It is evident that the 400CVDT10 visually has a "sharper curve," suggesting that this cyclone was able to achieve an improved d50 cut point and therefore better efficiency when compared to the 400CVXT10. The sharpness of separation is reflected by the gradient of the efficiency (or partition) curve near the cut size (d50). A steeper gradient indicates a sharper separation, suggesting that the hydrocyclone is more effective at differentiating between fine and coarse particles. The sharpness index (often referred to as "imperfection index I") can be calculated using the particle sizes at which 75% (d75), 50% (d50) and 25% (d25) of the feed report to the underflow. A lower imperfection index reflects a more efficient cyclone. From these results, the 400CVDT10 displays a lower sharpness index when compared to the 400CVXT10, suggesting a superior separation efficiency. Comparison of imperfection index between the two hydrocyclones are shown in Table 4.

Table 4: Imperfection Index of 400CVDT10 and 400CVXT10

Hydrocyclone Type	Imperfection Index
400CVDT10	0.25
400CVXT10	0.34

4 Benefits to the customer

When compared with 400CVXT hydrocyclone, new 400CVDT improves two aspects of classification: (i) can achieve similar cut size (P80) at a lower operating pressure (ii) reduce the fine bypass in the underflow. With the data presented in the Table 5 it is possible to conclude that the use of CVDT can improve techno-commercial feasibility of coal beneficiation process with additional sustainability benefits and minimised footprint of the 400CVDT10 cyclone. In the event of the client needing to increase their feed flowrate, Simulation 5 highlighted that an additional cyclone would need to be installed in the case of the 400CVXT10. This would incur an additional 30% cost to the original purchase price of the three 400CVXT10 cyclones.

Table 5: Classification performance between 400CVXT10 and 400CVDT10 hydrocyclones

	400CVXT10	400CVDT10
Hydrocyclone Diameter (mm)	400	400
Vortex Finder (mm)	150	140
Operating Pressure (kPa)	79	60
Feed Solid Concentration (wt. %)	25	25
Corrected Cut size (d_{50c})	147	147
Overflow P80 (μm)	118	124
Mass Split to OF %	26.9	26.9
Fine Bypass %	21	6.3

When compared with Cavex®400CVXT, the Cavex® 400CVDT hydrocyclone has direct financial benefits including minimization of annual maintenance cost due to improve wear life. The following table shows a comparative calculation of annual maintenance cost due to wear life. Based on data showed in Table 6, the client can potentially benefit to have a 20% cost saving per year by using the CAVEX® 400CVDT10 second-generation hydrocyclone.

Table 6: Annual maintenance cost comparison between 400CVXT10 and 400CVDT10

Annual maintenance costs based on wear life	400CVDT with Operating pressure 60kPa	400CVXT with Operating pressure 79kPa
	R 131 424.00	R 164 736.00
Annual savings	20%	

5 Conclusion

Hydrocyclones play an integral role in particle separation in coal applications. Recent technological advancements, including the optimisation of existing cyclone designs, have significantly improved their performance. The second-generation CAVEX® 2 hydrocyclone, for instance, offers enhanced particle separation and improved flexibility to accommodate for higher flow rates, which can lead to potential cost savings. These improvements further the potential to maximise recovery and capacity in coal beneficiation plants. By analysing a case study that compares the performance of the first-generation CAVEX® hydrocyclone against that of the second generation, it is evident that new developments in cyclone

technology and design have contributed positively to the industry by offering a more efficient and sustainable particle separation solution. In the case of the 400CVXT10 versus the 400CVDT10 cyclone, the 400CVDT10 proved to be the better choice.

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