Improved classification with the Cavex® DE hydrocyclone for mill circuit, coarse particle flotation, and tailings applications

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ABSTRACT

The Cavex® DE hydrocyclone is presented, which incorporates two stages of classification in a single device with no intermediate pumping. Experimental and pilot test campaign results show the Cavex® DE hydrocyclone can replace a two hydrocyclone cluster system for coarse particle flotation (CPF) feed preparation. Comparisons of classification performance between the Cavex® DE hydrocyclone and a single stage hydrocyclone at a copper-gold operation in Queensland are presented. Advancements in modelling technique to support selection and optimisation of the Cavex® DE hydrocyclone is also presented, including new methods. Advanced techniques used in optimising the design are described, including multi-phase computational fluid dynamics (CFD) with Lagrangian and Eulerian approaches for coarse and fine particle tracing respectively. CFD modelling was first validated using industrial scale tests, and then used in optimising designs and selection methodology. Some details on example historic application of Cavex® DE technology, as well as new industrial scale test results and optimisation, is provided. This includes example tailings applications, and an application in a Chilean grinding circuit with CPF. The effective generation of separate slimes and sand streams with high recovery is presented, supporting the beneficial use of tailings in impoundment construction. The flexibility inherent in Cavex® DE technology, with its array of interchangeable options and configurations, provides the industry with an adaptable, high performing classifier in the various applications listed above. The test results and operational data presented show the benefits in performance available to the industry.

INTRODUCTION

The Cavex® DE hydrocyclone integrates a two-stage separation process within a single unit. The design incorporates a primary hydrocyclone with a cylindrical section transitioning into an inverted conical section (Figure 1). The bottom chamber has wash water injection feeding a secondary hydrocyclone. An optional air core booster (ACB) can be installed atop each hydrocyclone to support the vortex and air core.

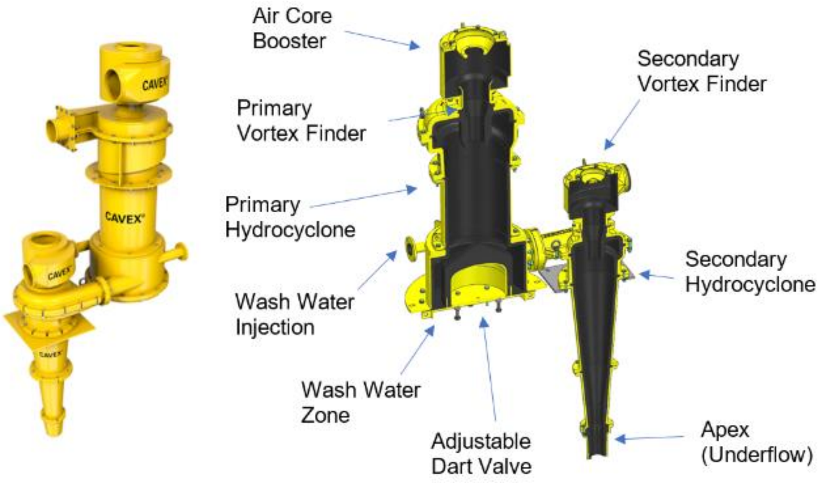

FIG 1 – Cavex® DE hydrocyclone.

The Cavex® DE hydrocyclone's design simplifies operations by eliminating the need for additional pumps, sumps, or civil structures, reducing both capital and operational expenses. The adjustable conical valve influences the distribution of mass between the two stages, optimising cut size and underflow fine and coarse particle size distribution. It acts like an adjustable spigot for the first stage of classification. The wash water zone and chamber smoothly delivers the slurry to the secondary classification stage. It does this in a smooth manner, reducing turbulence, pressure loss, and wear. The addition of wash water is instrumental in determining the cut size of the hydrocyclone, impacting the proportion of underflow fines and the performance of the secondary stage. Distinctly, the Cavex® DE hydrocyclones wash chamber is segregated following the initial classification stage, thus ensuring a controlled, two-stage separation process. Both stages of the Cavex® DE hydrocyclone employ the inlet geometry that was shown to significantly improve both wear life, as well as classification performance, in site measurements taken in trials against older designs (Warman International, 1998). Note the Cavex® DE model number is designated by the first and second stage hydrocyclone diameters in millimetres (mm), respectively, eg 250/150 Cavex® DE.

A comparative analysis of a single-stage hydrocyclone and a Cavex® DE hydrocyclone under identical feed and slurry conditions (to ensure an unbiased assessment) is presented in this paper. The 250/150 Cavex® DE hydrocyclone's secondary stage hydrocyclone, employed in the comparative test work, was configured to mirror the single-stage Cavex® hydrocyclone, providing a consistent basis for evaluating performance differences. The effects of water injection are significant to the performance of the Cavex® DE hydrocyclone, as it influences the slurry density, cut size, and the mass recovery of the final hydrocyclone stage. The effects of water injection are detailed in this paper.

This paper also details several current installations of the Cavex® DE hydrocyclone, especially in tailings and in Latin America, offering insights into their operation. In the construction of tailings storage facilities, it is possible to separate and utilise a free draining sands portion of a tailings stream to support the construction of embankments (depending on the feed particle size distribution). This reduces the overall requirements of tailings management. This is often achieved via hydrocyclones. According to Kujawa (2011) the 'free-draining characteristic of the sand is defined by the mass fraction of particles of less than 75 µm. This is a concept borrowed from the soil sciences where by definition free drainage occurs at a particle mass fraction of 5 per cent passing 75 µm. The definition has been amended for tailing dam construction to slightly higher percentages by mass passing 75 µm, with 15 per cent being common, 18 per cent considered on the high end'. The Cavex® DE hydrocyclone will later be shown to be an excellent desliming solution for such applications.

Another application well suited for Cavex® DE technology described in this paper is in the feed preparation for coarse particle flotation (CPF). Eriez HydroFloat™ CPF is a technology that offers the ability to highly effectively recover valuables at coarse sizes, offering the ability to achieve coarse gangue rejection and thus pre-concentration. This therefore also results in lower energy consumption in comminution. The HydroFloat™ cell 'works on combining the principals of flotation with hindered settling… [and] the key characteristic of the HydroFloat™ cell is the presence of an aerated fluidised bed' (Vollert, Akerstrom and Seaman, 2019). As CPF is less effective at separating fine material, and since fine material below -75 µm can disrupt the function of the HydroFloat™ cell, fines need to be removed from the feed to CPF; target limits for the percentage of solids mass below -75 µm in the feed can often be circa 10 per cent. Therefore, similarly to tailings, the Cavex® DE hydrocyclone is examined in this paper as a solution to CPF feed preparation requirements.

In what follows, the selection and optimisation of the Cavex® DE will be first introduced, including modelling approaches, computational fluid dynamics (CFD) results, and also a summary of recent industrial scale tests that have been used to further improve selection and optimisation methods. Next, comparisons between Cavex® DE and a single stage hydrocyclone are made. Finally, some details are provided for different applications, including in CPF and in tailings processing.

SELECTION AND OPTIMISATION OF CAVEX® DE HYDROCYCLONES

In this section the methodology developed for selecting and optimising the performance of Cavex® DE hydrocyclones is discussed. First the methodology is described, and then some guidance is provided for optimisation.

Modelling and selection methodology

Recent further advancements in the methodology used to predict and optimise the performance of the DE hydrocyclones involved several steps, including extensive test work at the Weir Technical Centre (WTC) in Melbourne Australia, full surveys of the hydrocyclones four slurry streams, and model development. The methodology was also informed through CFD analysis. Slurry samples collected from the hydrocyclone feed sump at a nickel mine concentrator were utilised (primary semi-autogenous grinding (SAG) grinding circuit product) for the portion of the test work reported in this section, as well as other sites and historic data. This test regime and model development methodology considered variables available for selection (eg hydrocyclone geometries and wash water addition). The methods developed further support optimisation and scaling of the hydrocyclone, and provides further guidance for greenfield selection and brownfield optimisation.

CFD analysis was also carried out and indicated no upstream backflows originating from the DE hydrocyclones lower chamber into the primary stage in the conditions reviewed; a full and controlled two stage classification is achieved. This observation aligns with the water mass balance derived from WTC test results. Based on these observations, a two-stage modelling approach has been adopted for performance prediction and optimisation. In lieu of Weir's internal selection and optimisation tools, a two-stage modelling approach could be performed in an application such as JKSimMet® using the following two steps, as an initial estimate of performance. The listed process models could also be applied, which are further described in Napier-Munn (1996):

- First Stage: Employing the 'Single Component Efficiency' model.
- Secondary Stage: Employing the 'Nageswararao' model.

Additionally, the model incorporates a water addition, representing the primary lower chamber. This addition aids in regulating the pressure control and solid concentration for the secondary hydrocyclone feed. It achieves this by enabling precise control over the water volumetric flow rate and secondary feed percent solids. External calculations are used to inform the model parameters of the first stage, as the geometry is dissimilar to conventional hydrocyclones. Full surveys, including of both overflows separately, and pressure measurement at the feed to the second stage, allow for model fitting in both stages. This approach is illustrated in Figure 2.

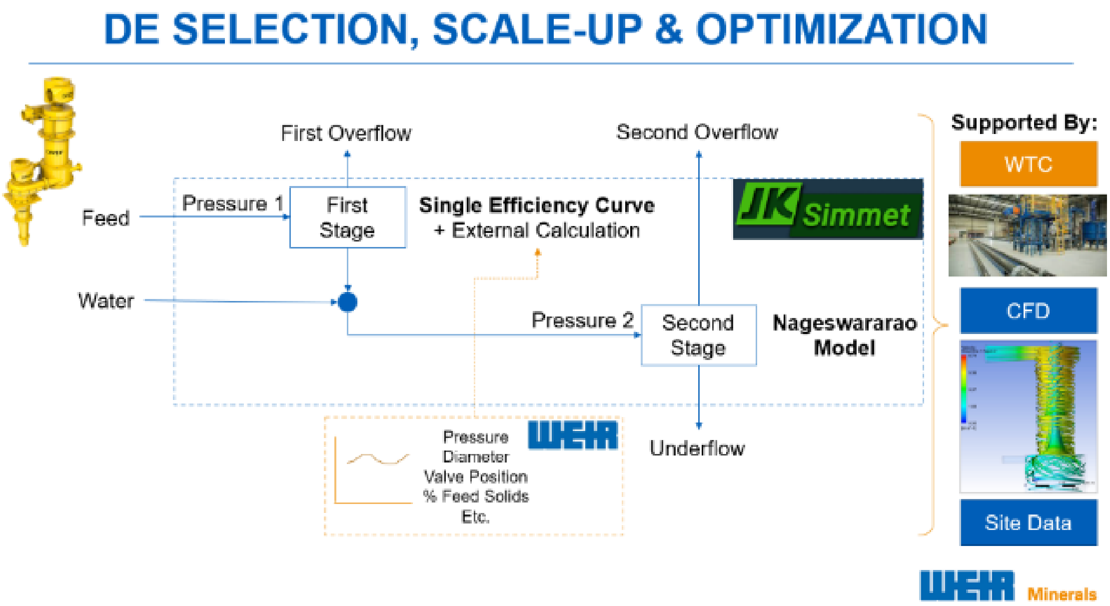

FIG 2 – Cavex® DE selection, scale-up and optimisation modelling approach.

CFD model description

CFD was used to analyse the hydrocyclones performance. As described above, it was used to establish the validity of a two-stage modelling approach, and to improve design and modelling approaches. Slurry flows in hydrocyclones can be described as a multiphase flow, consisting of various sizes of ore particles in a slurry media. This mixture of coarse and fine particle slurry travels inside hydrocyclone system creating a turbulent flow. It is also necessary to capture the air core. These complex flows can be solved by a number of CFD techniques. These include the full Eulerian multiphase approach, simplified Eulerian approaches such as the mixture and VOF models, and the Lagrangian approach. For this work multiphase Eulerian and Lagrangian approaches were used for fine and coarse particle tracing respectively.

The Eulerian model is the most complex of the multiphase models in Ansys Fluent CFD, the package used in this work. It solves a set of *n* momentum and continuity equations for each phase. Coupling is achieved through the pressure and interphase exchange coefficients. The manner in which this coupling is handled depends upon the type of phases involved; granular (fluid-solid) flows are handled differently than nongranular (fluid-fluid) flows. For granular flows, the properties are obtained from application of kinetic theory. Momentum exchange between the phases is also dependent upon the type of mixture being modelled.

Given that in a complex slurry structure like the one modelled, there is a range of particle sizes from ‘fines’ to ‘coarse’. Therefore, for relative simplicity, a number of different particle classes are selected to reasonably represent the size distribution of the slurry stream. These selected size classes were represented as multiple granular phases along with water as primary phase.

Example illustrations of CFD results are shown in Figure 3, showing the primary stage and wash chamber, and these mirrored the test conditions at the WTC. The streamline plot (a) shows the outside coarse materials travel, and the internal upward vortex that carries the fine material to the overflow. The lower figures (c) and (d) show the smooth transition to the secondary stage that reduces turbulence, wear, and pressure loss to the next stage. It can be seen from the figures that this is supported by the design and action of the wash water injection.

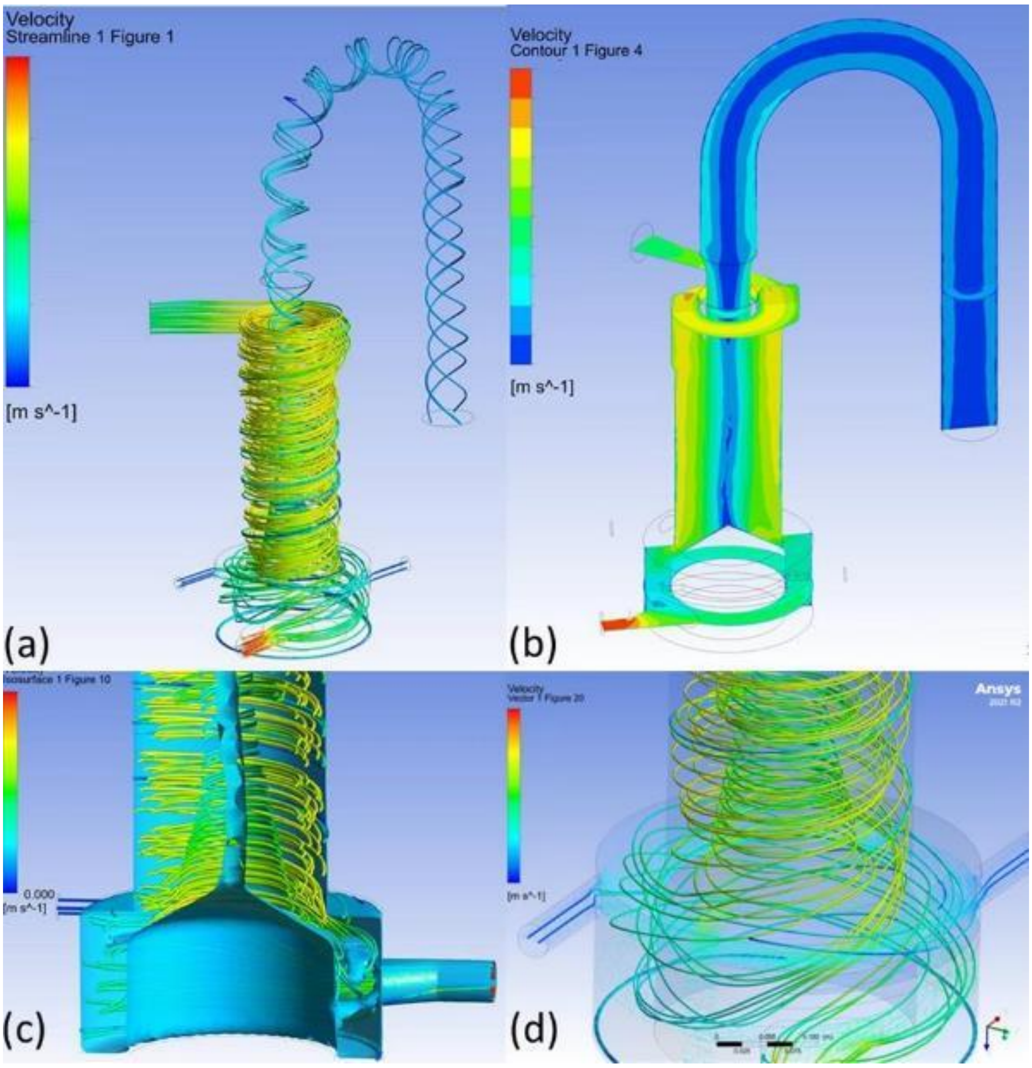

FIG 3 – Cavex® DE hydrocyclone CFD modelled flow velocity field and stream lines showing the primary stage and lower chamber.

Figure 4 shows the modelled flow velocity vector near the dart valve between the first stage and the wash chamber. Flow is out of primary stage, into the wash chamber, and supports the two-stage modelling approach (described above). The streamlines in Figure 5 also supports this observation, with flush water directed to the next stage.

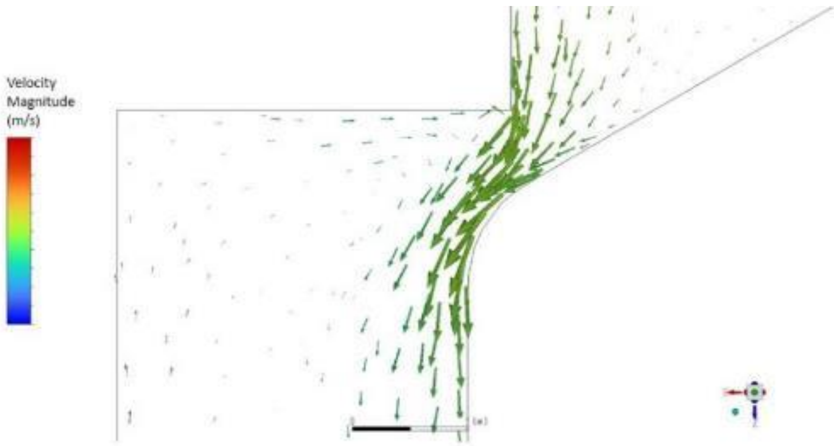

FIG 4 – Cavex® DE hydrocyclone CFD modelled flow velocity vector shown mid plane near the gap.

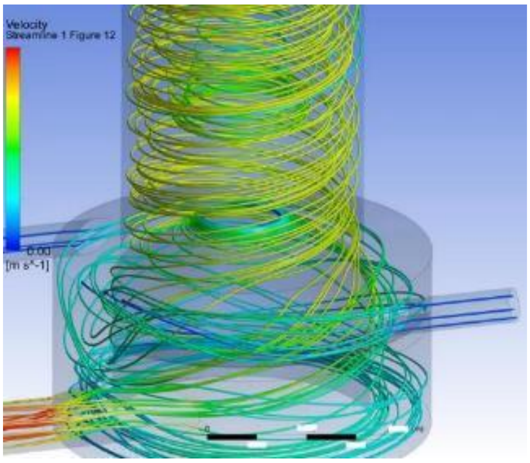

FIG 5 – Cavex® DE hydrocyclone CFD modelled flow streamlines.

In conclusion, the CFD methods used to improved design and selection methodology have been described and illustrated. In the next section, the industrial scale test work that accompanied this is also summarised.

Industrial scale tests – feed conditions and variables

The industrial scale test work and surveys conducted at the WTC in 2022 will now be described. Initially two variables, namely the feed dry tonnes per hour (tph) rate to the primary hydrocyclone and water injection rate to the wash chamber, were tested while keeping the geometric configuration unchanged (as shown in Tables 1 and 2). The solid concentration in the feed remained approximately constant at 55 per cent by weight. The performance of the primary hydrocyclone was primarily influenced by the feed rate. Whereas the percent solids and the feed rate both varied and affected the performance of the secondary stage hydrocyclone. The mass balanced data of the WTC test results can be seen in Table 3.

TABLE 1

Hydrocyclone geometries used in the WTC tests.

	Primary hydrocyclone	**Secondary hydrocyclone**
Cyclone diameter	250 mm	150 mm
Vortex finder	100 mm	60 mm
Gap size	30 mm	N/A
Spigot size	N/A	25 mm
Inlet diameter	73 mm	41 mm

TABLE 2

Independent variables tested.

Independent variable	**Values (mass-balanced)**
Water injection*	2, 4, 6, 11%
Feed t/h (dry)	46.4–81.0

TABLE 3

Feed condition and mass-balanced data.

Data set		L2 P2	L2 P3	L2 P4	L2 P5	L2 P6	L2 P7	L2 P8	L2 P9	L2 P10
Feed	t/hr	46.37	66.28	76.79	46.82	80.82	78.32	81.04	79.17	75.45
Primary operating pressure	kPa	78	151	209	84	210	212	210	209	205
Secondary operating pressure	kPa	56	95	127	58	128	128	127	128	123
% Solids primary feed	%	52.9	54.8	55.8	55.3	55.5	55.8	55.1	55.4	58.2
% Solid secondary feed (calculated)	%	61.7	65.7	67.3	60.9	65.7	64.7	64.3	60.4	56.7
Total feed volumetric flow rate	m^3/hr	58.2	78.8	88.8	54.9	96.1	94.2	101.2	102.5	81.6
Water injection % to secondary hydrocyclone*	%	0	0	0	0	2%	4%	6%	11%	0

*% of DE slurry feed volumetric rate.

Greenfield modelling guidelines based on above test work

Observations from the test work above provide some insight into Greenfields modelling of the DE hydrocyclone, and these will now be described. Note that these observations relate to the test work described in Table 1 through Table 3, which is limited to a single application rather than a stipulation on general performance, so only the general trends will be described. As described above, to simulate a Cavex® DE hydrocyclone, a two-stage modelling approach in JKSimMet can be applied. The subsequent sections will now cover the major model parameters required for this modelling approach.

Primary hydrocyclone parameters (single component efficiency model)

The primary hydrocyclone geometry is not the same as a conventional hydrocyclone, and so the single component efficiency model in JKSimMet is used rather than other models based specifically on conventional geometry. All model parameters were fitted using this approach for the primary hydrocyclone, and alpha, water split, and D50c were calculated from the test data described in this paper. Responses to each independent variable (eg water injection rate, vortex finder size etc) were tested.

Alpha selection

In the primary stage, the feed rate fluctuated without displaying any significant trend in relation to alpha. The alpha values in the primary stage were observed to vary between magnitudes similar to conventional single stage hydrocyclones. For greenfield projects, similar alpha values for the first stage could be utilised to what is seen in conventional single stage hydrocyclones as a preliminary guideline when more precise estimates are not available.

Water split to O/F selection

For the primary hydrocyclone, the water split to the overflow (O/F) ratio was observed to be within the 63–70 per cent range when operating pressures varied between 100 kPa and 210 kPa in the tests per Table 3. This was based on a consistent solid concentration of 55 per cent in the feed during tests conducted at the WTC. An upward trend in the water split ratio to O/F was noted with increasing pressure. Other data shows that as feed solid concentration reduces, the water split increases (eg in examples with the feed in the 35–45 per cent range, water split increases to 80 per cent). For applications in greenfield projects, this commentary can provide some guidance, and water splits in the first stage of the Cavex® DE are not dissimilar to those obtained in conventional single stage hydrocyclones.

D50c selection

In lieu of Weir's internal toolset, as a first estimate, it might be assumed the 'Nageswararao' model can be employed to provide an indication of the D50c response for the primary stage of the DE hydrocyclone for various sizes and feed pressures. This prediction assumes scaling from the same feed slurry, and the same primary hydrocyclone shape. It also assumes that the nongeometric terms in Nageswararao's empirical model will have the same exponents and terms, despite them being developed for quite a different geometry. For operation with different feeds and geometries (eg vortex finder to hydrocyclone diameter ratios) judgement is required for D50c calculation. With the assumptions above, much of the empirical formula of the Nageswararao model D50c calculation (Napier-Munn, 1996) can be simplified to a single new constant defined in this paper, C_J, specific to like geometry ratios and the same feed characteristics. The ore characteristics and feed conditions need to be considered with care.

$$D50c = C_J \left(\frac{D_o}{D_c}\right)^{0.52} D_c^{0.57} \lambda^{0.93} \left(\frac{P}{\rho_p g}\right)^{-0.22} \quad (1)$$

$$\lambda = 10^{1.82C_v}/(8.05[1 - C_v]^2) \quad (2)$$

where:

C_J	= A constant determined from experiments for the primary stage
λ	= Hindered settling correction term
Cv	= Volumetric fraction of solids in feed slurry
g	= 9.81 (m/s^2)
D50c	= in m
P	= Operating pressure (kPa)
ρ_p	= Slurry density (t/m^3)
D_o	= Vortex finder (m)
D_c	= Cylinder diameter (m)

This modelling approach was applied to the test work of Table 3, and appears capable of predicting the D50c using the equation given for operating pressures within a ranging of where it was fitted (from 120 to 210 kPa in this study). However, it is important to proceed with caution when predicting performance at operating pressures well outside of the fitted range as it becomes more difficult to predict the D50c.

Secondary hydrocyclone simulation (Nageswararao Model)

As the CFD analysis showed, no flow back into the primary hydrocyclone appears to occur past the dart valve, thus typical Cavex® hydrocyclone behaviour is expected in the secondary stage hydrocyclone. The 'Nageswararao' model can be chosen to simulate the second stage as a first estimation, by including the wash water and the first stage underflow as combined feed, and it provides the ability to simulate performance changes due to adjustments in operating pressure and hydrocyclone dimensions, as well as scaling.

Water split and wash water injection

It was observed that increasing water injection improves the water split to O/F ratio of the secondary hydrocyclone, which in turn improves the classification of fines. However, as the water injection rate was further increased, the gradient of this improvement in fines classification appears to diminish.

Cyclone optimisation

The following sections provides supporting detail on key selections for the Cavex® DE hydrocyclone.

Guideline for primary/secondary VF finder and spigot size selection

The selection of these parameters is critical to achieving the best performance, and should be tailored to the specific characteristics of the feed, ore properties, and the desired process objective. Weir has completed extensive testing and can support the optimisation of these parameters based on the measured results obtained.

Cyclone pressure optimisation

Primary hydrocyclone pressure recommendation

Results from the WTC tests indicate that the most effective hydrocyclone classification efficiency occurs when operating pressures at the primary hydrocyclone inlet in a similar range to those typical of conventional hydrocyclones, and in the tests conducted in Table 3, improved classification was seen at pressure ranging between 120–160 kPa. If there's a need to make the P_{80} of the global underflow coarser, elevating the pressure in the primary hydrocyclone is a suitable approach. For greenfield, using tools such as Weir CySelect, flow and pressure curves, or any other available resources is advised. These instruments assist in determining the operating pressures aligned with specific flow rates, providing valuable insights into the most fitting hydrocyclone geometries.

Secondary hydrocyclone pressure recommendation

For the secondary hydrocyclone, optimal fines removal in the underflow has been linked to the use of the largest VF sizes coupled with higher operating pressures (100–130 kPa). This set-up exploits the complex relationship between the two hydrocyclone stages, where the secondary hydrocyclone's pressure is typically 70–90 per cent of the primary stage feed pressure (in the tests run). A suitable pressure range in the secondary hydrocyclone has been identified as key to efficiently separate fines, based on WTC test outcomes.

SINGLE VERSUS CAVEX® DE HYDROCYCLONE PERFORMANCE

A comparative study of single stage 150CVX hydrocyclone versus 250/150 Cavex® DE hydrocyclones was carried out. This work was based on test work conducted at WTC under similar conditions. Another key focus of this study was evaluating the hydrocyclones' performance based on variations in the water injection rate into the secondary hydrocyclone. Insights derived from this comprehensive analysis were subsequently leveraged to meet the prerequisites for CPF preparation, details of which are discussed further in the following sections.

The analysis included a survey of each hydrocyclone arrangement utilising identical slurry samples (see Figure 6 for the PSD comparison) from a tailings feed from a Copper mine. This method ensured the data sets were comparable, with each maintained at a uniform pressure of 150 kPa. A data set from the 150CVX was chosen to specifically match the configuration of the secondary hydrocyclone of the DE system (also a 150CVX model), as detailed in Table 4.

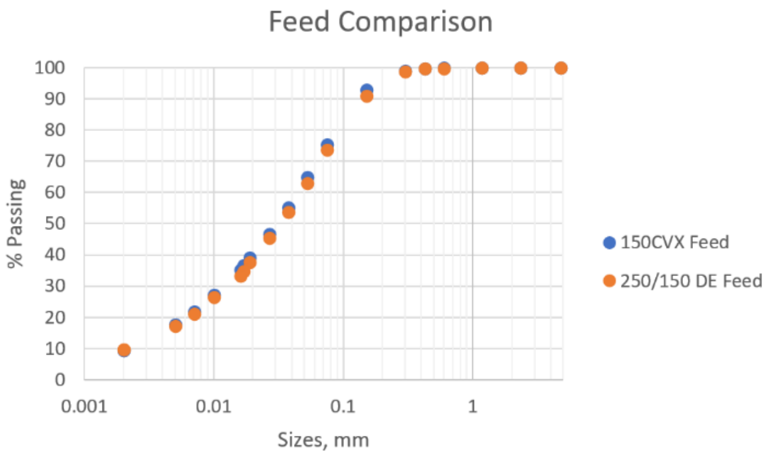

FIG 6 – Feed comparison.

TABLE 4

Single stage hydrocyclone and DE hydrocyclone configuration.

	Single-stage hydrocyclone	**Cavex® DE hydrocyclone**
Configuration	150CVX	Secondary Stage of the DE (150CVX)
VF (mm)	60	60
Spigot (mm)	25	25

The analysis focused on the underflow and overflow PSDs, represented in Figures 7 and 8, which indicate that the 250/150 Cavex® DE hydrocyclone achieved a lower percentage of sub 75 µm sized particles in the underflow (29 per cent) compared to the 150CVX hydrocyclone (50 per cent). This was achieved while maintaining similar overflow PSDs across both data sets. This can also be seen in Table 5. This result indicates the 250/150 Cavex® DE hydrocyclone's improved performance in fines desliming.

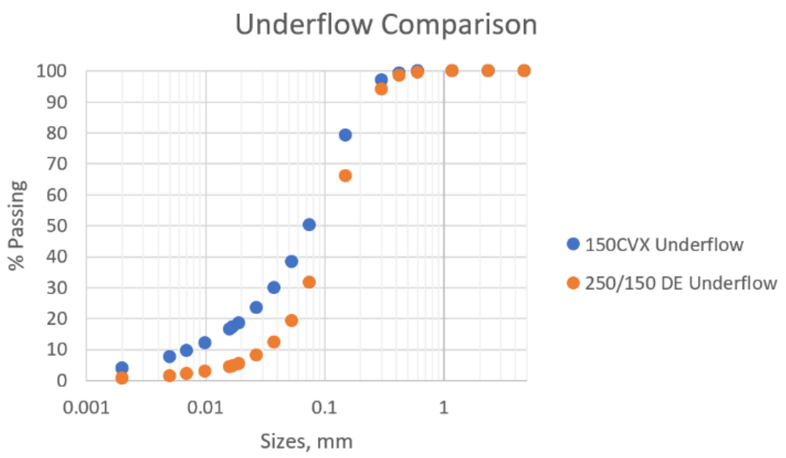

FIG 7 – Underflow comparison.

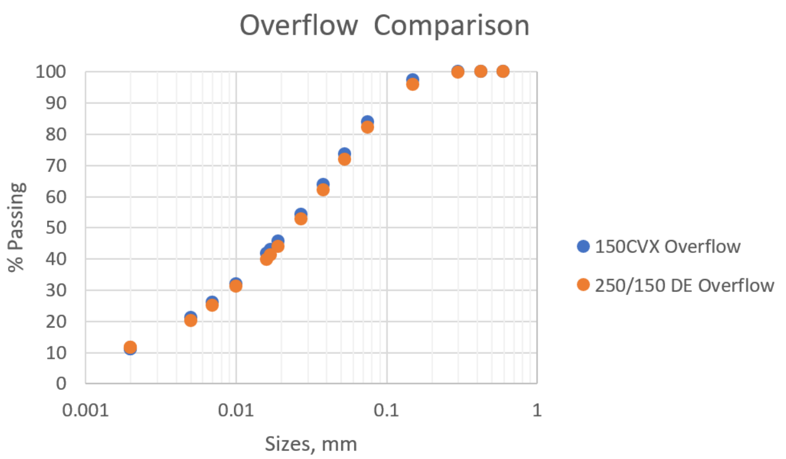

FIG 8 – Overflow stream comparison.

TABLE 5

Cumulative passing of sub 75 µm.

Cumulative passing of -75 µm	F_{80} (µm)	U/F (%)
250/150 Cavex® DE	87	29
150CVX	87	50

The recovery of fines (particles smaller than 75 µm) in both the overflow and underflow streams were also examined (Table 6). The Cavex® 250/150 DE hydrocyclone demonstrated a solid recovery of sub 75 µm particles of approximately 93 per cent from feed to O/F stream, compared to 84 per cent for the 150CVX. This indicates a notably better recovery of fines for the Cavex® 250/150 DE hydrocyclone.

TABLE 6

Mass split/recovery of solids sub 75 µm from feed.

Mass split/recovery of sub 75 µm from feed	To O/F (%)	To U/F (%)
250/150 Cavex® DE	93.0	7.05
150CVX	83.5	16.5

A comparison of the recovery of coarse particles larger than 75 µm indicated that the Cavex® 250/150 DE hydrocyclone had a 62 per cent recovery for coarse materials, compared to a higher rate of 72.4 per cent for the 150CVX (Table 7). This suggests that while the DE hydrocyclone demonstrated superior performance in fine particle classification, attention needs to be placed on maintaining coarse material recovery to the U/F stream (perhaps given the larger diameter of the primary stage in this example) relative to the single stage hydrocyclones; note that the DE hydrocyclone primary VF size can also be adjusted.

TABLE 7

Mass split/recovery of solids larger than 75 µm from feed.

Mass split/recovery of +75 µm from feed	To O/F (%)	To U/F (%)
250/150 Cavex® DE	37.8	62.2
150CVX	27.7	72.4

The observed data indicates a decrease in the overall percentage of mass recovery of solids from feed to U/F stream when comparing the Cavex® 250/150 DE hydrocyclone versus 150CVX as indicated in Table 8. This decrease in the mass recovery aligns with expectations given the improved fine particles classification. Consistent with predictions, there was a marked increase in the quantity of fines reporting to the overflow.

TABLE 8

Total solid mass recovery % from feed to U/F stream comparison.

Overall percentage of solid mass split/recovery from feed	To U/F (%)
Cavex® 250/150 DE	16.4%
150CVX	24.8%

The water balance will now be considered. The Cavex® DE hydrocyclone demonstrates a significant advantage over single-stage hydrocyclones in terms of reduced water bypass to the underflow. In the scenario presented in Table 9, the Cavex® DE hydrocyclone achieved an underflow solids content of 86 per cent, compared to 78 per cent for the 150CVX (Table 10). While this high solids concentration may indicate a condition close to roping, this can be mitigated by adjusting the spigot and vortex finder configurations. Notably only 3 per cent of the total process water reported to the underflow for the 250 Cavex® DE hydrocyclone, compared to approximately 10 per cent for the 150CVX. Moreover, under suitable feed conditions, the water balance of the Cavex® DE hydrocyclone allows its combined overflow to be suitable for conventional flotation, with a solids content of 48 per cent in this example (Table 9).

TABLE 9

Water balance.

	250/150 Cavex® DE	150CVX
Total water volumetric flow rate (m^3/hr)	67	20
% Solids U/F	86	78
% Solids O/F	48	55
Water bypass to U/F (% of total)	3	10

TABLE 10

Cumulative passing % of sub 75 µm – Site B Test.

Lowest cumulative passing % of sub 75 µm in the underflow stream	
Site	**Cumulative passing % of sub 75 µm in the underflow**
Site B (F_{80} of 253 µm)	12.9%

In summary, the Cavex® 250/150 DE hydrocyclone demonstrated superior performance in fine particle removal, with 29 per cent of cumulative passing of sub 75 µm particles in the underflow, compared to the 150CVX's 50 per cent. It achieves performances that would otherwise require multiple stages of conventional hydrocyclones with associated increased CAPEX and OPEX costs associated with the intermediate pumping. However, a slight increase in coarse material loss was observed with the 250/150 Cavex® DE hydrocyclone compared to a single-stage hydrocyclone (likely due to the large primary stage and coarser cut). The Cavex® DE hydrocyclones improved capability in fines removal significantly contributes to the overall quality and classification efficiency improvement, producing a coarser product P_{80} of 199 µm versus 153 µm with the single-stage 150CVX hydrocyclone.

The effects of water injection to the secondary hydrocyclone

Figure 9 illustrates the relationship between the wash water injection rate, expressed as a percentage of the total feed volume rate to the primary stage, and the cumulative % mass passing of sub 75 µm in the underflow of each sample. The data indicates that an increase in the water injection rate correlates with a reduction in the fine particle content within the underflow. Consequently, the water injection rate can act as a controllable variable to vary the fines content in the underflow to meet specific targets, such as CPF feed preparation or free drainage for tailings impoundment considerations. However, the overall mass recovery of solids may be affected by variation in the water injection to the secondary hydrocyclone, as seen in Figure 10. The wash injection influences the slurry density and feed rate to the secondary cyclone and hence influences its cut size. In another operation, increasing wash water addition was observed to produce a finer overflow at a given feed pressure, while keeping other operating conditions unchanged. Increasing wash water was also seen to reduce the solids concentration of the underflow and increases the mass recovery to underflow (Banerjee *et al,* 2023). These observations are then consistent across these different operations.

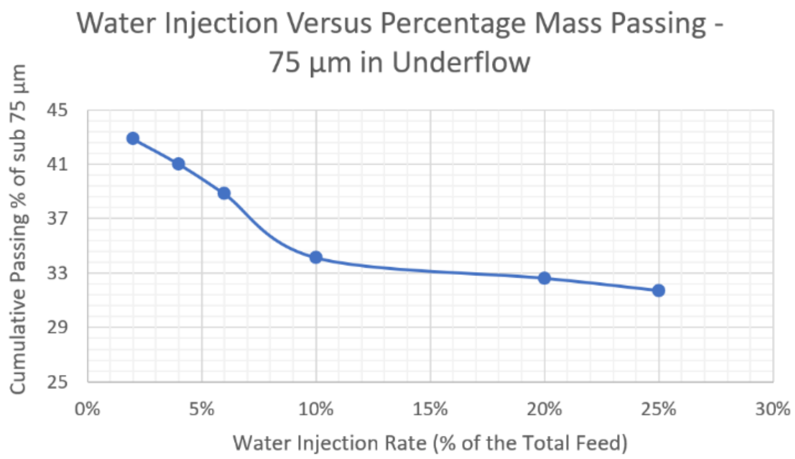

FIG 9 – Water injection rate versus sub 75 µm passing in underflow.

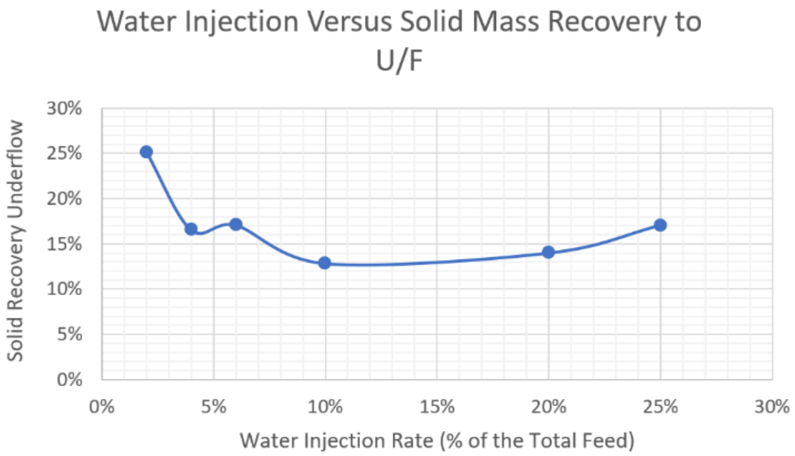

FIG 10 – Solid mass recovery to U/F stream.

CAVEX® DE APPLICATIONS

Having introduced the Cavex® DE hydrocyclone, described its modelling, selection and optimisation methods, and having compared the Cavex® DE against a single stage hydrocyclone, we will now review some example applications in the following part of the paper. This will include CPF feed preparation first, followed by examples in tailings. Finally, an example list of installations is provided.

CPF feed preparation

Weir is targeting sub 10 per cent mass passing of -75 µm in the Cavex® DE hydrocyclones underflow stream for feed preparation to CPF. Achieving this could eliminate the necessity for the Eriez CrossFlow classifier in CPF plants, and added classification stages, improving CAPEX and OPEX performance. Through testing at the WTC, application of the Cavex® DE hydrocyclone has been specifically studied for CPF feed applications, and an example further set of test work from another site (Site B) is now provided. This application was from a relatively fine grinding circuit product, which was fed to the Cavex® DE hydrocyclone. An underflow cumulative mass passing -75 µm of 12.9 per cent was achieved, while the P_{80} of the feed was 253 µm, per Table 10. This was achieved at relatively low wash water percentage (12 per cent). From subsequent test results showing the continued improvement with increasing water injection rate (refer to Figure 9), the target of below

10 per cent passing of sub 75 µm is expected to be achieved with increased water injection and cyclone configuration improvements. Cavex® DE hydrocyclones have also been employed in CPF feed preparation after semi-autogenous grinding (SAG), and prior to regrinding, at a Chilean Copper mine.

Weir Minerals Australia (WMA) designed and manufactured a Cavex® DE classification pilot test rig that can be integrated with Eriez Australia's HydroFloat CPF pilot test rig. This combined classification and CPF pilot test rig can be transported to sites across the region for piloting. Most recently, Weir and Eriez Australia conducted a pilot plant study to evaluate the Cavex® DE pre-classification and HydroFloat CPF at Northparkes Mine (NPM); a copper and gold mine in central New South Wales. Survey data was collected from December 2023 to May 2024, and assessed the performance of the hydrocyclone to prepare CPF feed and CPF performance itself from both 'coarse' (primary ball mill hydrocyclone overflow), and 'fine' (scavenger tails) feed sources. Some photos of the pilot test rig are shown in Figure 11.

FIG 11 – Cavex® DE hydrocyclone and Eriez HydroFloat® Pilot test rigs.

Tailings applications

The Cavex® DE hydrocyclone has been extensively employed successfully, especially in tailings applications, and especially in Latin America, for particle size classification and dewatering. Many of these applications employ the DE hydrocyclone in desliming of tailings to generate sand for tailings wall construction. It is also used as a classifier in regrind applications, and for CPF feed preparation. Figure 12 shows an example image of a Cavex® DE hydrocyclone cluster installation. Table 14 shows just some examples of the extensive list of successful applications in tailings. The next section also provides two more detailed examples of Cavex® DE hydrocyclones operating on tailings feeds (Case Study A and B).

FIG 12 – Cavex® DE hydrocyclone cluster installation examples (bottom) and in a tailings facility in South America (top).

Detailed Case Study A

Hydrocyclone test work was carried out with a tailings sample from a gold-copper mine, 'Site A', at the WTC. The use of the Cavex® DE hydrocyclone resulted in an enhanced water split (93 per cent) to the overflow stream compared to traditional hydrocyclones (70–90 per cent). A fine classification improvement was observed, attributable to an improved water split within the hydrocyclone, which led to a significant reduction in the cumulative percentage of particles smaller than 75 µm in the underflow stream, achieving 14 per cent. The measured data from this application was modelled fitted as a single stage hydrocyclone by combining the overflow streams, and by using the 'Single Component Efficiency Curve Model', which characterises the hydrocyclones performance by three overall performance parameters: sharpness of the cut (alpha), water split % to overflow stream, and D50c cut size. This modelling approach is further described in Napier-Munn (1996).

The DE hydrocyclone showed superior separation efficiency, as indicated by the alpha value in the efficiency curve. The calculated alpha value for the Cavex® DE hydrocyclone was 4.7, markedly higher than the typical range of 2 to 2.5, when model fitted with the single efficiency curve model. A variety of slurry samples with varying feed conditions were also trialled. The volumetric flow rates of the hydrocyclone feed and underflow streams are recorded and measured using the flow metres installed. The density and the PSD data of each stream was measured. Table 11 includes an example feed condition used.

TABLE 11

Feed conditions.

	Site A Cavex® DE hydrocyclone
Feed t/h (dry)	40.2
% Solids, feed	43
Volumetric flow rate, m^3/hr	68
Pressure, kPa	100
SG (specific gravity)	2.71

The survey data from the WTC was mass-balanced and then model-fitted in the JKSimMet process modelling environment. The Cavex® DE hydrocyclone modelled in JKSimMet as a single-stage hydrocyclone, to compare its performance parameters with those of the conventional hydrocyclone, is shown in Figure 13. The Single Component Efficiency Curve Model performance parameters can be seen in Table 12.

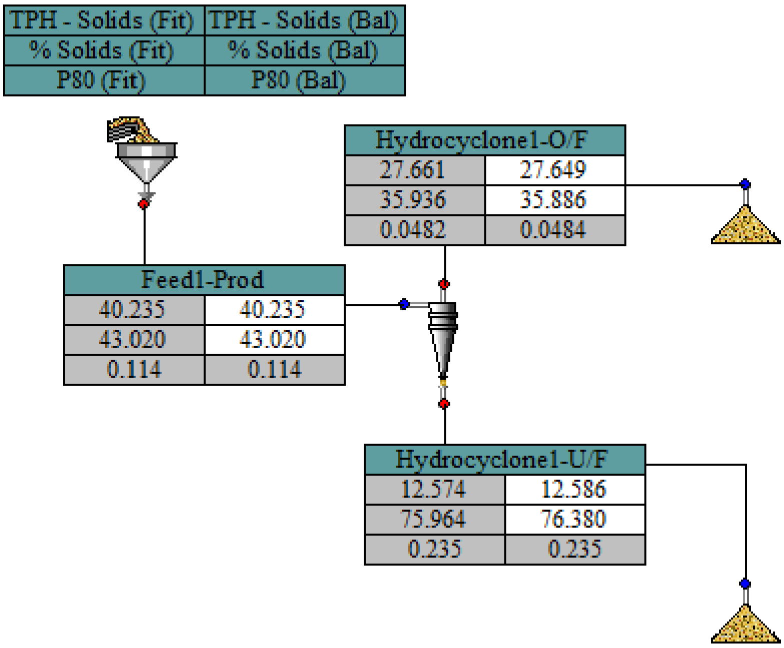

FIG 13 – Tailings Cavex® DE survey model-fitted as a single stage hydrocyclone.

TABLE 12

Cavex® DE performance parameters.

	Site A
Combined alpha	4.7
D50c (µm)	98
Water split % to O/F	92.5
Combined P_{80} (µm) O/F	48
Feed P_{80} (µm) to Primary Cyclone	114

The industrial standard performance parameters of typical single stage hydrocyclones are alpha's of 2–2.5, and water splits of 70–90 per cent, with D50c varying depending on the dimensions and the slurry conditions. Therefore, based on the survey results, the Cavex® DE hydrocyclone shows excellent performance in these surveys, and for tailings desliming duties.

Detailed Case Study B

The second tailings case study of a Cavex® DE application is taken from literature (Banerjee *et al,* 2023) and is summarised here. This case study related to the pilot scale operation of a Cavex® 500/400 DE (500 mm diameter primary stage and 400 mm diameter secondary stage) processing a sulfide copper tailings feed with a high proportion of slimes (F_{80} of 200 µm, 50 per cent solids concentration by weight, 47 per cent solids mass below -75 µm, at a feed pressure of 103 kPa). The objective was to reclaim a sand product for the purpose of supporting the construction of a tailings dam embankment, and to recover as much water as possible. An underflow solids of sub 75 µm of 17 per cent by mass was achieved in the underflow. The same operation achieved 12 per cent sub 75 µm by increasing feed pressure to 138 kPa. This represents an efficient result on tailings desliming. Table 13 shows the Cavex® 500/400 DE geometry used in this application, and Figure 14 shows the PSDs achieved.

TABLE 13

Cavex® DE hydrocyclone geometry in Case Study B (after Banerjee *et al,* 2023).

Table 3. DE hydrocyclone geometry used for pilot scale testing.

Dimension	Primary	Secondary
Hydrocyclone diameter (mm)	500	185
Inlet diameter (mm)	211	145
Vortex finder diameter (mm)	185	130
Spigot diameter (mm)		70
Cone angle		10

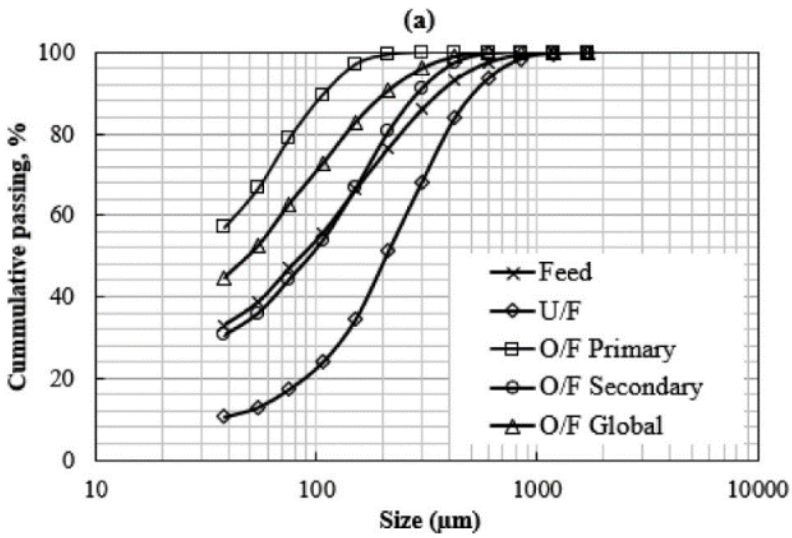

FIG 14 – Cavex® DE hydrocyclone PSDs in Case Study B (after Banerjee *et al,* 2023).

Example installation list

Table 14 shows an example list of installations of Cavex® DE hydrocyclones, in various sizes and cluster configurations.

TABLE 14
Example installations.

Location	Application	Additional information	Model	Cluster quantity	Hydrocyclones per cluster
Latin American Mines	Tailings	Wall construction	500/400CVX-DE	1	12
	Tailings	Wall construction	500/400CVX-DE	3	6
	Tailings	Wall construction	500/400CVX-DE	1	20
	Tailings	Sand Deposit	500/400CVX-DE	2	18
	Tailings	Wall construction	500/400CVX-DE	2	22
	Tailings	Sand Deposit	400/250CVX-DE	1	5
	Tailings	Sand Deposit	400/250CVX-DE	1	5
	Tailings	Sand Deposit	650/500CVX-DE	1	9
	Tailings	Sand Deposit	500/400CVX-DE	1	4
	Tailings	Sand Deposit	500/400CVX-DE	1	8

CONCLUSIONS

The Cavex® DE two stage hydrocyclone was presented, which was shown to achieve the efficiency of two stage classification without the CAPEX and OPEX of intermediate pumping. Experimental and pilot test campaign results showed the Cavex® DE hydrocyclone can replace a two hydrocyclone cluster system for CPF feed preparation, and also achieves the desliming required for free draining tailings sand production, even with quite fine feeds. Overall, the Cavex® DE hydrocyclone demonstrated substantial improvements in fine classification, higher performance parameters, and separation efficiency. It resulted in better classifications for especially the fine material which is critical in CPF and tailings hydrocyclone sands applications. While in the tests and feeds included at the time of writing this paper, CPF feed preparation still required further configuration optimisation to reach the <10 per cent -75 µm solids mass goal for fine feeds, the data presented supports this can be achieved with increased wash water and changes in hydrocyclone configuration.

Direct comparisons of classification performance between the Cavex® DE hydrocyclone and a single stage hydrocyclone were presented, demonstrating the improved performance of the Cavex® DE which resulted in fewer underflow fines (-75 µm) and an increased recovery of coarse product to the underflow, thereby improving fine classifications, compared to a single stage hydrocyclone. The single stage hydrocyclone demonstrated less efficient separation by comparison, although the total mass recovery to the underflow was higher, which could be due to more misclassifications of fine materials to the underflow.

Advancements in modelling technique to support selection and optimisation of the Cavex® DE hydrocyclone were described, which have employed CFD, pilot testing, and industrial scale laboratory testing. Guidance on making first estimations of Cavex® DE performance was also provided, as were some details on selection and optimisation. Furthermore, the influence of significant variables such as cyclone geometries and wash water injection rate etc, on performance were explored.

Example historic application of Cavex® DE technology, as well as new industrial scale test results and optimisation, was provided. This included some detailed examples in tailings applications, and a list of example installations. The flexibility inherent in Cavex® DE technology, with its array of interchangeable options and configurations, provides the industry with an adaptable, high performing classifier in the various applications listed above. The test results and operational data presented show the benefits in performance available to the industry. The Cavex® DE hydrocyclone was demonstrated in this paper to offer excellent classification performance in the various applications reviewed.

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