TAKING CARE OF YOUR PLANT'S CYCLONES IN ORDER TO TAKE CARE OF YOUR PLANT

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ABSTRACT

With a very rich and colourful history in South Africa, the coal industry has reached a point where the quality of coal resources is declining and differs quite significantly from the coal that was mined 30, 40 and 50 years ago. On top of that it also seems however that the level of experience in the industry may be declining. To maintain and improve the efficiency of the process and to operate the Coal Processing Plant (CPP) at a more economically rewarding level, it is necessary to refresh operational personnel's understanding of how an integral piece of CPP equipment, like the cyclone (both dense medium and classification) work, the factors impacting on its performance and common mistakes that are observed in the industry on a frequent basis.

This paper will briefly describe the impact that poor dense medium cyclone performance has on material with various levels of near density material and its economic impact. It will also discuss the effect of varying feed conditions and the influence on cyclone efficiency for hydro cyclones on a high level. Although cyclones have a fairly simple design with no moving parts, the effect they have on a plant's overall performance is staggering, and we therefore cannot afford them to be operated at a substandard level with the modern coal reserves.

Furthermore, common field observations will be discussed and the impact it can have on the operation of the cyclone unit as well as the overall process. Where relevant, the observations will include other pieces of equipment as well. Most of these observations are preventable and can be quite easily corrected if plant personnel understand the equipment's working principles, respect their function in the CPP and know what to look out for.

The paper concludes by looking at some of the tools used by Multotec to do cyclone inspections onsite, specifically the use of a 360º VR camera which reduces inspection time drastically and gives detailed imagery of the internal wear surfaces.

With a focussed and disciplined approached it is still possible to extract sufficient value from modern low-grade coal reserves.

BACKGROUND

From the very beginning humans investigated natural phenomena and the manipulation thereof for our own advantage. It is therefore no surprise that the manipulation of centrifugal forces in classification applications by means of hydrocyclones dates back to even before 1890. In 1891 a 43-year old Eugene Bretney filed a patent for a water purifier (Bretney, 1891) which would turn out to be an early ancestor of the cyclones (hydro- and DMS) we still use to this day in our processing plants. As can be seen from the following drawing, taken from Bretney's patent, the cyclone as we know it today has evolved over the past 130 odd years.

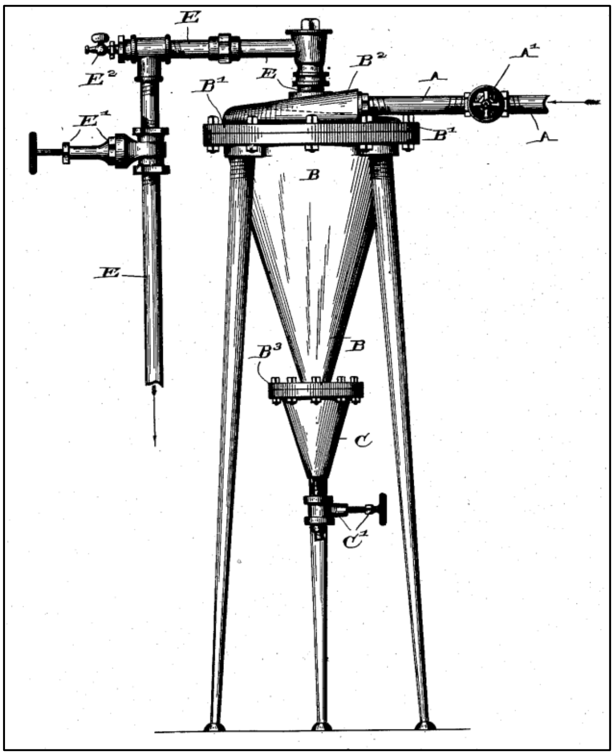

Figure 1: Bretney's design for a water purifier (Bretney, 1891)

Between 1900 and 1937, 30 additional patents were issued for the use of devices resembling the hydrocyclone of today. According to Smith (2000:3) the first commercial application of the hydrocyclone came about in 1937, when hydrocyclones were sold for cleaning sand and dirt particles from fibre suspensions in the pulp and paper industry. By 1940, hydrocyclones as we know them today, made an appearance in the paper and pulp as well as coal washing industries. At the same time, Maximiliaan Driessen, of the Dutch State Mines (DSM) was working on hydrocyclones for thickening and classification of slurry streams (Bradley, 1965). The Dutch State Mines hydrocyclone was first commercially implemented in the US in 1948.

The DSM continued with their ground-breaking work in the development and application of cyclones in specifically coal processing plants and in 1946 Driessen *et al.* (1951) filed the very first patent for a dense medium separation (DMS) cyclone. Although the patent describes using loess (a type of sand), instead of the magnetite we use today in DMS applications for coal, the principles developed by the DSM still form the basis of for all modern DMS cyclone designs (Singleton, 2013:27).

Cyclones (and specifically the DMS cyclone) have become the key processing unit in coal processing plants since its development more than 70 years ago (de Korte, 2012:2). With its capability of efficient separations, ease of operation and accurate control, it has proven itself as a workhorse in the coal processing industry. Unfortunately, a lot of processing plants neglect the operation, maintenance and sizing of their installed cyclones. This may be due to their relative simplistic design, the fact that they don't have any moving parts or even complacency or a lack of proper understanding from those who operate them. Nonetheless, with South African coal reserves which get more difficult to separate, yielding less product and at lower product qualities (Enslin, 2017:3), it is of utmost importance to ensure that the heart of the coal processing plant (the cyclones) is performing optimally to improve the plant's economic viability.

This paper focuses on some of the common mistakes and practices seen on a regular basis at various coal processing plants, how it affects the plant overall and what can be done to fix the situation.

THE DENSE MEDIUM CYCLONE'S ROLE IN THE COAL PROCESSING PLANT

Below is a simplified flow diagram of a coal processing plant commonly found in the Witbank coalfields. This plant consists of a Coarse and Smalls Low Gravity circuit (producing the higher quality coal, 6000kcal/kg or 5500kcal/kg) from which the sinks are collected and fed to the High Gravity circuit (producing the lower quality coal, 5500kcal/kg or 4800kcal/kg). There are also however examples where the floats (and not the sinks) of the primary DMS circuit is fed to the secondary DMS circuit so that the higher quality coal is produced in the secondary circuit. Choosing this configuration will depend on the specific plant's washabilities and the cyclones' underflow capacities. The fines are beneficiated by means of spiral classifiers and with the assistance of hydrocyclones. There are also plants that may cut a bit coarser on their desliming screens than the 1mm used in this example, but the fact remains that the +1mm (or even sometimes +2mm) material is normally processed by means of dense medium separation and then specifically using DMS cyclones. Although there is a magnitude of different coal processing plant configurations available, the basic principles remain the same and since the plant described here and depicted below is very common for the Witbank coalfields specifically, the examples given in this paper will be based on this plant configuration. It is however possible, without great effort, to adapt the examples and calculations given in this paper for any specific coal processing plant under consideration.

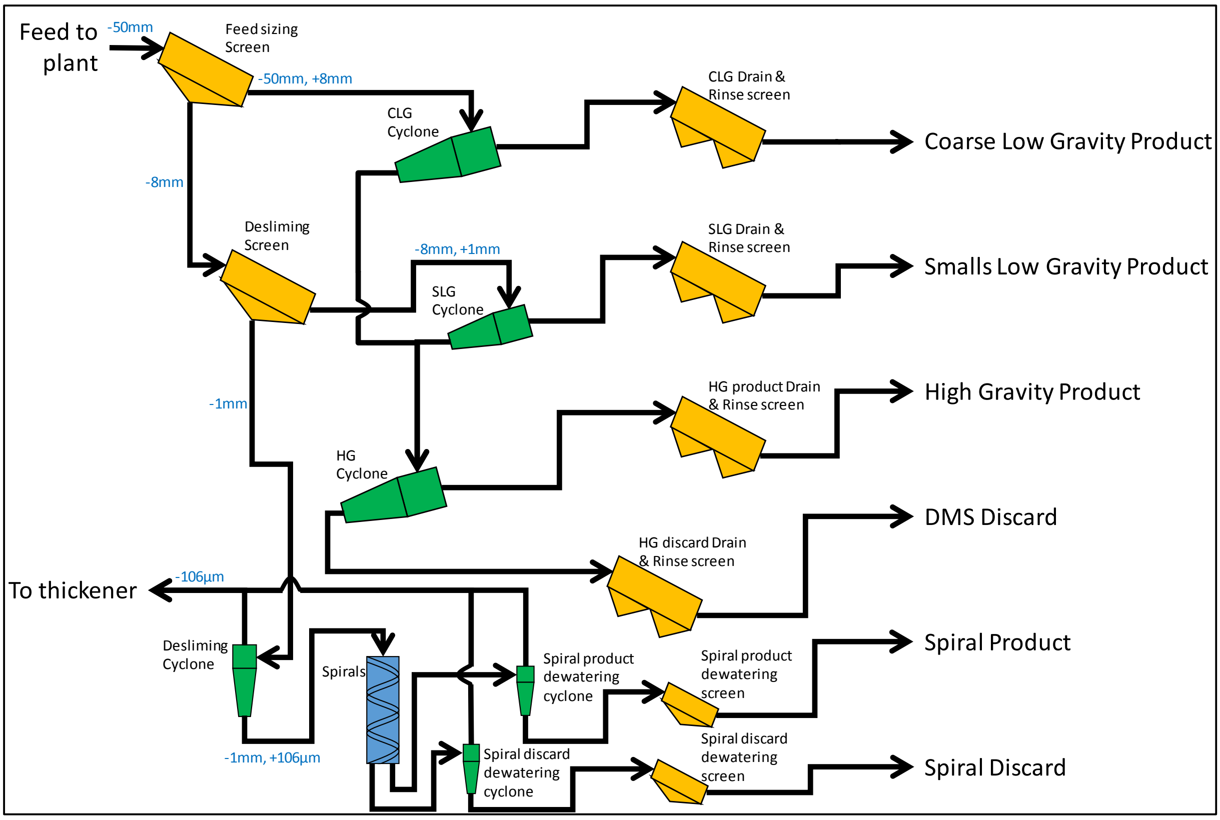

Figure 2: Simplified flow diagram of a common coal processing plant in the Witbank coalfields.

Based on several samples taken of the feed to various coal processing plants, the particle size distributions indicate that the fines (-1mm material) represents anything from 2% to 33% of the total feed to the plant. This means that 67% to 98% of the total feed to the plant will be beneficiated in the plant's DMS circuit. For the sake of the example and calculations to follow, a figure of 80% will be assumed, but as can be seen from the following graph, this figure may vary significantly.

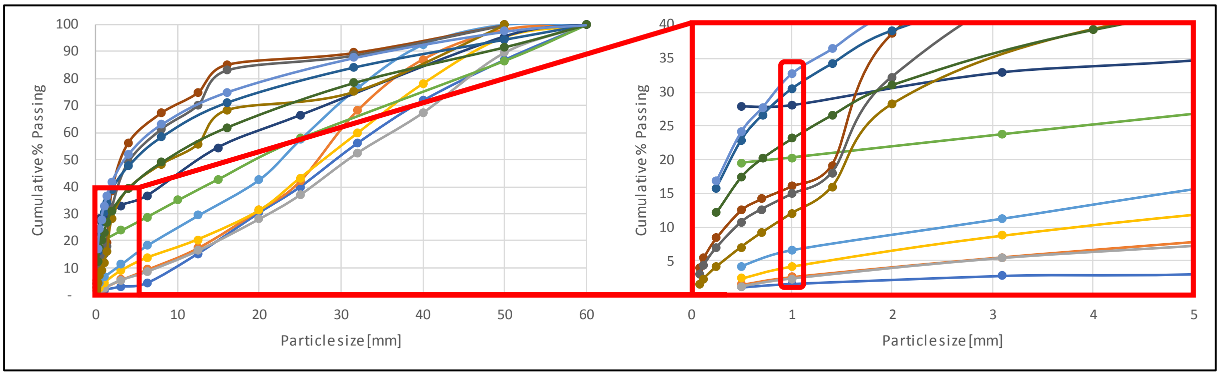

Figure 3: Particle size distributions of the feed to various coal processing plants.

With a few basic assumptions (based on what is happening in reality) it becomes an easy calculation to quantify exactly how important dense medium cyclones are in the economic viability of a coal processing plant. The following assumptions are made for the calculation to follow:

Table 1: Assumptions made for profit creation calculation.

Feed to plant (FTP)	1,000	tph
Portion fed to DMS cyclones	-50, +1	mm
Portion of FTP fed to DMS cyclones	80	%
Expected DMS cyclone product yield	70	%
Revenue per saleable ton (4800kcal/kg)	R850	

Based on these assumptions, one can expect 560tph of product passing through the cyclones (1000 x 80% x 70% = 560tph). At a selling price of R850/t the potential revenue created by the dense medium cyclones is in the order of R132/sec (R850 x 560tph ÷ 3600sec/hr = R132.22). Should we assume that you would require 2 x 1000mm cyclones to beneficiate this coal and that the profit for selling the coal is only a mere 15%, the profit generated by a single 1000mm cyclone under these conditions is enough to pay for that cyclone in just more than a single shift's time (R300,000 ÷ (R132.22 ÷ 2 x 15%) = 8hrs 25min). Generating a profit in the order of R10/sec it becomes clear why it is worthwhile to ensure the cyclone is operating optimally.

As mentioned previously, if 80% of the total feed to plant (-50, +1mm) is processed by means of Dense Medium Separation (and then specifically DMS Cyclones), 1% misplacement of floats to the underflow for a 1000tph CPP (producing a 4800kcal/kg product) relates to a potential loss of revenue in the order of R104,000 per day. These are only typical values for a coal processing plant in the Witbank-coalfields, so for more variance in the %Fines (-1mm) in the FTP, product yield achieved by the DMC and misplacement of floats to the cyclones' U/F, consider the following graphs.

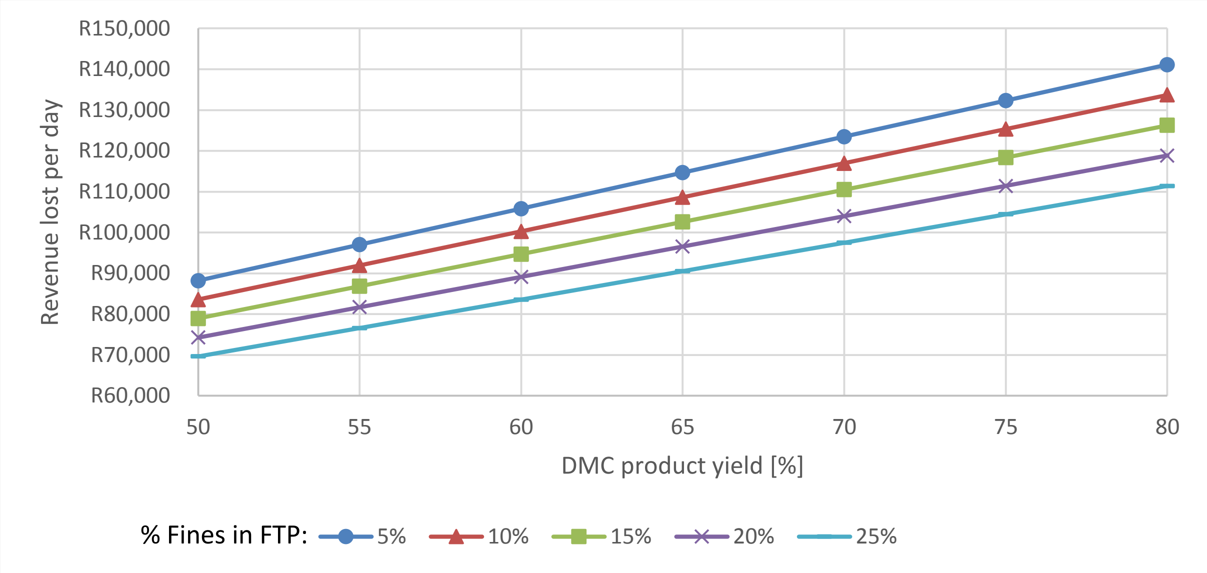

Figure 4: Possible revenue loss for a 1000tph plant with a 1% misplacement of floats to the U/F at various DMC yields and fines (-1mm) in the FTP.

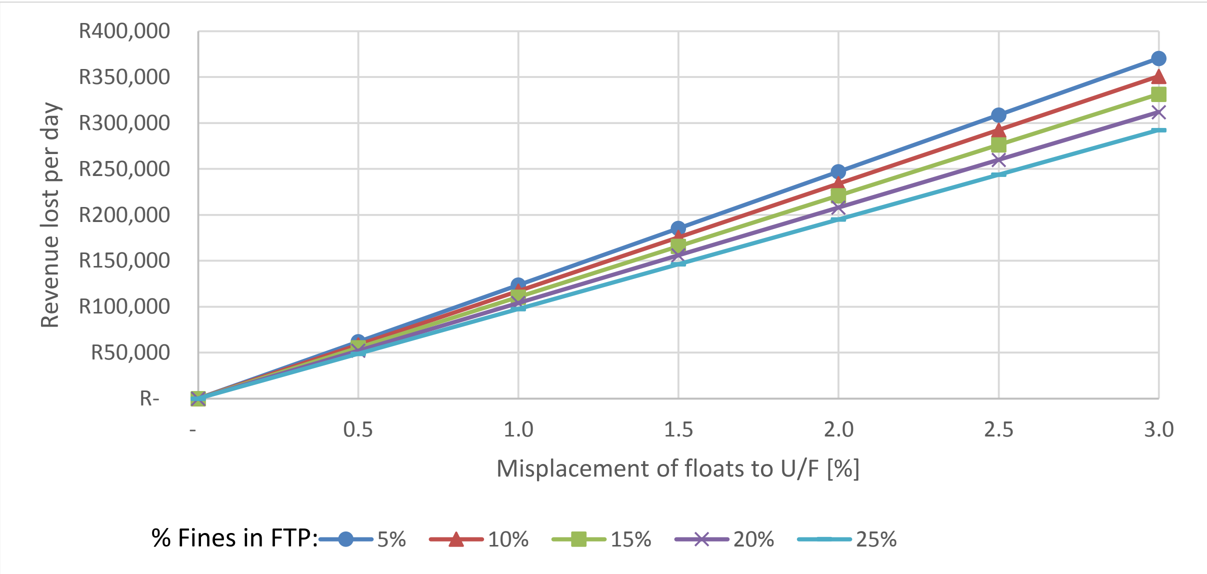

Figure 5:Possible revenue loss for a 1000tph plant with a 70% DMC product yield at various floats to U/F misplacements and fines (-1mm) in the FTP.

Now that it is clear what the potential gains are for operating a cyclone optimally, it is important to identify and address situations and conditions that can contribute to the misplacement of product to the cyclone’s underflow and other aspects that can have a negative impact on the profitability of the specific plant.

Near density material is probably one of the biggest contributors to misplacement in a DMS cyclone. In fact, Claassen (2013:767) stated that the amount of near density material in the feed to a DMS cyclone is the single biggest variable that impacts DMS cyclone efficiency (in the region of 98%). Near density material is typically defined in

South Africa as those particles whose densities are within 0.1g/cm^3 from the specific separation density (Magwai & Claassen, 2013). There is however an alternative definition which choose to define the amount of near density material as those particles whose densities are within 0.05g/cm^3 from the specific separation density. For the sake of this paper the 0.1g/cm^3 variance definition is assumed. The following graph is a simplified indication of how near density material can be determined from washability data.

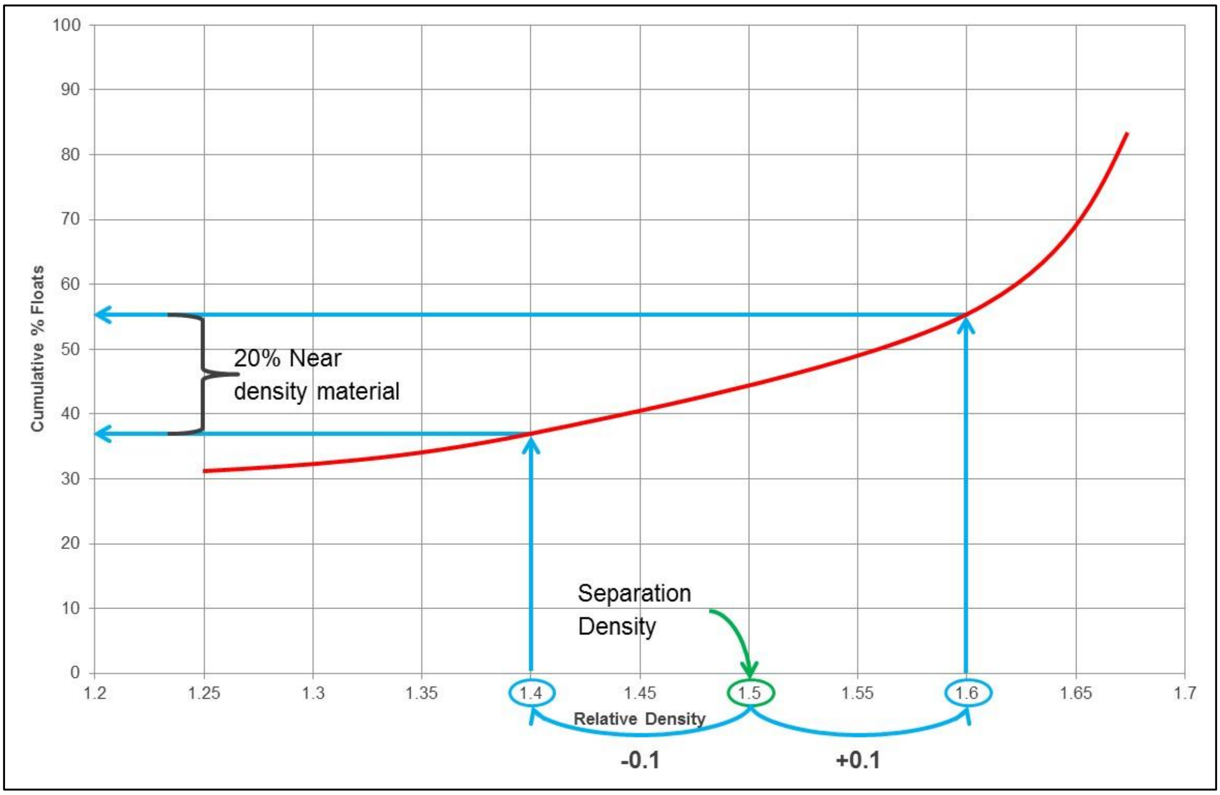

Figure 6: Simplified approach in determining near density material.

The impact of near density material on the DMS process has previously been reported to be mainly through a lowered organic efficiency and increased misplacement of particles in the DMS cyclone (Horsfall, 1987; de Korte, 2008). There is a direct relationship between the amount of near dense material in the feed to the DMS cyclone and the cyclone's ability to efficiently beneficiate the coal with minimal misplacement of particles, this relationship is quantified in the following table:

Table 2: Near density material with associated degree of difficulty of separation.

Near Density Material	Degree of Difficulty
0% - 7%	Simple
7% - 10%	Moderate
10% - 15%	Difficult
15% - 20%	Very difficult
20% - 25%	Exceedingly difficult
> 25%	Formidable

The following example illustrates the impact of near dense material on the amount of misplacement taking place in the cyclone. Below are two samples of washabilities to be processed in the same plant, through the same equipment and both washing for a product with 18.6% ash.

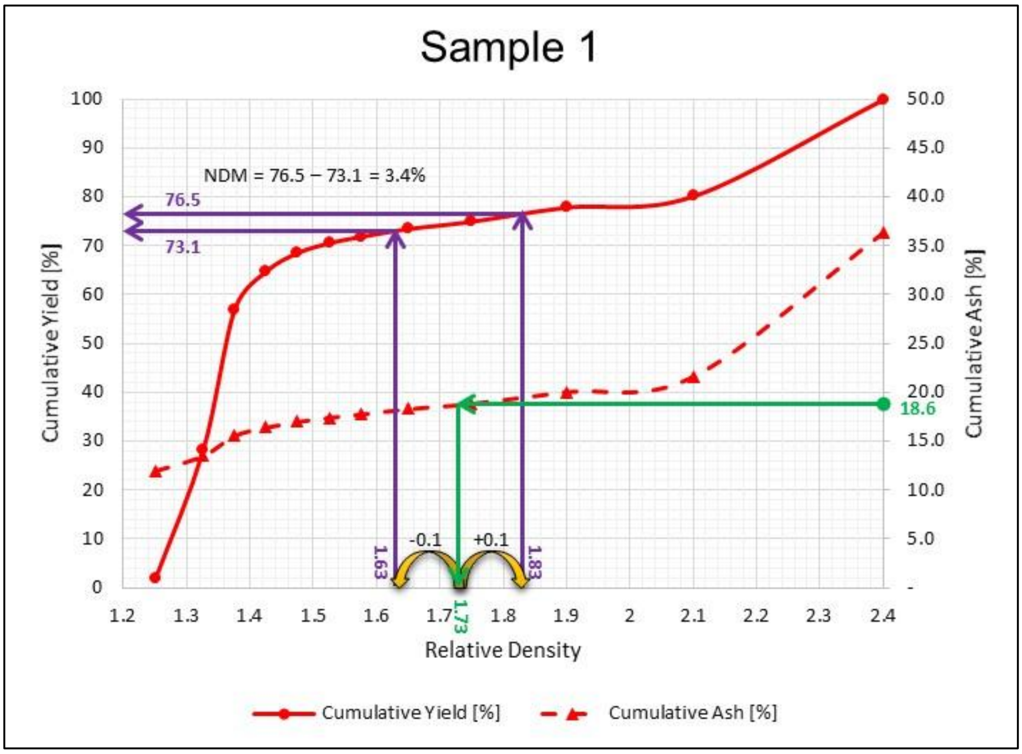

Figure 7: Washability data with low levels of near density material.

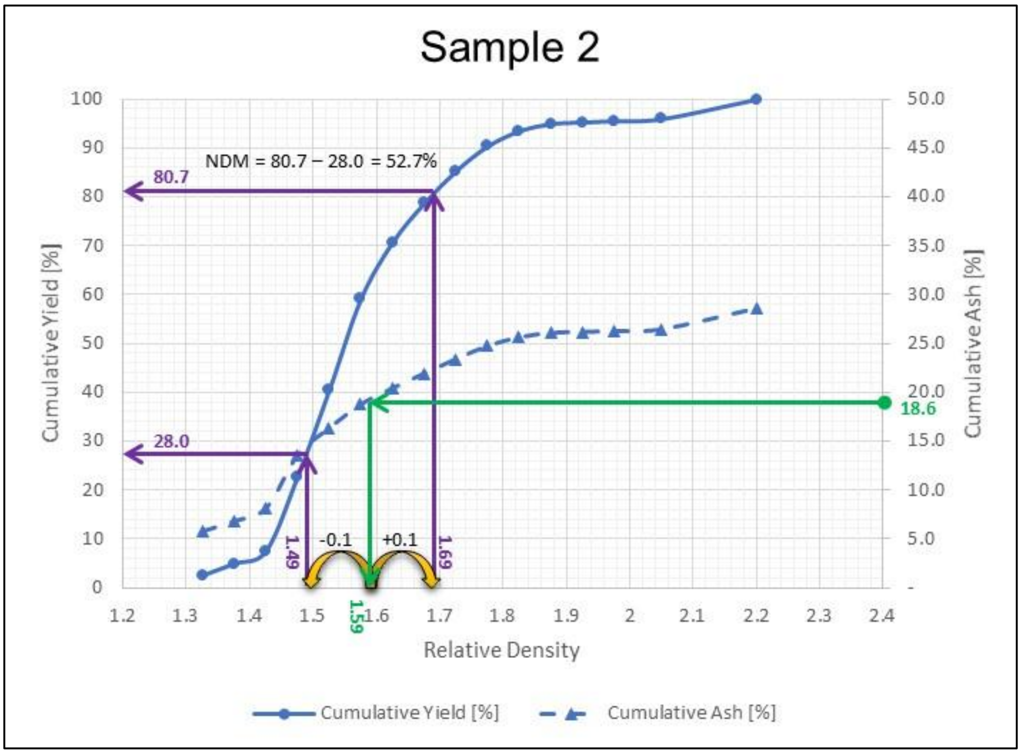

Figure 8: Washability data with high levels of near density material

Even though the DMS cyclone will be able to produce a 18.6% ash product with both samples and the product yield will be relatively similar (74% vs. 64%), the fact that Sample 2's near dense material is almost 50% more than that of Sample 1 (52.7% vs. 3.4%) results in the misplacement of floats to the spigot being almost 20 times higher for Sample 2. The misplacement of product to the cyclone's spigot for Sample 1 is a mere 0.1% whilst the same misplacement under similar operating conditions for Sample 2 is in the order of 2%. Note that near density material is a function of the specific cut density and is therefore directly related to the required product qualities and ore washability. Remembering that every 1% misplacement (in a 1000tph plant) of product to the cyclone's underflow relates to approximately R100,000 of potential revenue lost per day. These values quickly add up and over a month's time the effect on the plant's bottom line is tremendous.

With the amount of near dense material in the feed to the plant largely being a function of the site's specific geology and what the plant receives from Mining, there are fortunately still some opportunities the CPP can consider minimising the effect of high values of near dense material. According to Magwai & Claasen (2013:7) the measures to deal with excessive near dense material can be divided into two groups namely: changes around the DMS cyclone and then changes involving the feed to the cyclone. The four options under changes around the DMS cyclones include:

- Adding a barrel to the cyclone.
  A barrel is a straight cylindrical section added between the inlet head and top cone of a cyclone as indicated in the following schematic:

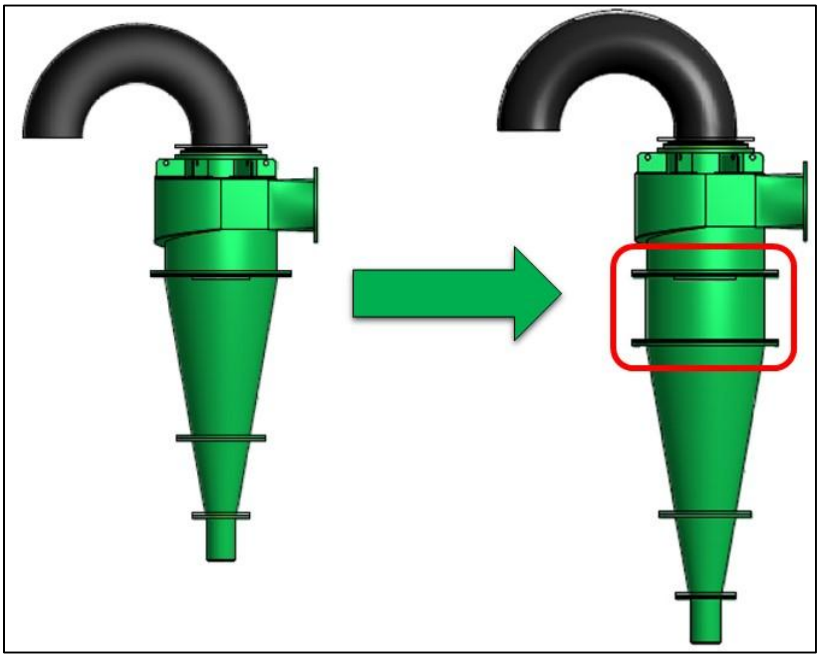

Figure 9: Addition of a barrel section to a cyclone.

By adding a barrel to a cyclone, one increases the cyclone's volume and therefor also the residence time of each particle being processed by the cyclone. Keeping in mind that the residence time of each particle in the cyclone is very limited, one can expect a greater probability that a particle will classify correctly if it gets a longer opportunity to do so.

Special care must be taken when considering adding a barrel to a cyclone however, because it could increase the cyclone's density differentials as well. The increase in density differentials will lead to an increase in the density cutpoint and this needs to be taken in account.

- Medium-to-ore ratio in the feed to the cyclone.
  The recommended medium-to-ore ratio (on a volumetric basis) when treating South African coal is 3.5:1 (Peatfield, 2003:363). Washing coal with relatively high near dense material at medium-to-ore ratios lower than the recommended 3.5:1 will result in inefficient cyclone operation and excessive misplacement. According to Magwai & Claassen (2013:7) there is however an upper limit beyond which further increase in the medium-to-ore ratio no longer makes a difference to the cyclone's efficiency but only reduces the cyclone's capacity. This upper limit for coal processing is in the order of 5:1.

- Spigot diameter.
  The two factors that has the biggest impact on a cyclone's capacity is the medium-to-ore ratio in the feed to the cyclone and the cyclone's "discard capacity" determined by it's spigot diameter. After a DMS cyclone has been sized by an OEM, great care should be taken before any changes are made to

a cyclone's spigot size since there are two opposing views on how the spigot size influences a cyclone's ability to effectively beneficiate ore with a lot of near dense material.

On the one hand, Sripriya *et al.* (2001) mentions that near dense material can build up inside the cyclone which can become a problem if the spigot is not large enough to discharge all the discard. In this case some of the discard particles can be misplaced to the overflow. Therefore, by increasing the spigot diameter, one can alleviate the load on the spigot and reduce misplacement of particles.

In contrast to this view, He and Laskowski (1995) believes that better separation efficiency can be achieved with smaller spigot diameters at the expense of lower cyclone throughput. The increased residence time of the feed particles in the cyclone due to the cyclone's lower throughput is said to improve their chance of reporting to the correct product streams.

When sizing a spigot it is important to take the following factors into account:

- Expected yields based on washability data;
- Volumetric capacity of a certain spigot at a certain feed head;
- The DSM principle of spigot ID to vortex finder ID ratio ≤ 0.8:1

- Cyclone diameter.

By increasing the cyclone's diameter, one also increases the unit's volumetric capacity and by keeping the solids throughput to the cyclone similar (to what was fed to the smaller diameter cyclone) you can operate the cyclone at a higher medium to ore ratio which will counter the effect of near dense material as previously discussed.

One also needs to keep in mind that although dense medium cyclones separate on a density basis they are still inherently classification cyclones with both the ore and medium being subjected to centrifugal and drag forces. The following formula is used to calculate the centrifugal forces acting on each particle in the cyclone, pulling the particle to the outside diameter of the cyclone:

$$F_C = \frac{m.v^2}{r}$$

Where: F_c = Centrifugal force [N]
m = mass of the particle [kg]
v = velocity of the particle [m/sec]
r = radius of the circular motion [m]

As can be seen from the formula, by increasing the diameter or radius of the cyclone, the centrifugal force acting in on each particle will reduce. This will cause less magnetite particles to migrate to the sides of the cyclone, causing a lower density differential and therefor also a lower cut density.

Furthermore, with the increase in the cyclone's diameter and the associated decrease in centrifugal forces as well as the limited residence time of a particle in the cyclone, the efficient separation of smaller particles will be influenced. The smaller centrifugal force acting in on the smaller particles, might not be sufficient to move them into the correct density zone in time before exiting the cyclone. The result is that bigger diameter cyclones will not separate smaller particles as effectively as the bigger particles in the same slurry stream. For each cyclone diameter there is a certain particle size (known as the breakaway size) at which separation efficiency starts to deteriorate. Please note that the breakaway size doesn't mean that the cyclone won't be able to separate particles smaller than that size, it simply means that the efficiency of separation will start to deteriorate for particles smaller than that cyclone's specific breakaway size. Breakaway size can be calculated with the following formula:

$$d_B = 6 \times Ø^{1.64} \times 10^{-5}$$

Where: d_B = Breakaway size [mm]
Ø = Cyclone diameter [mm]

It therefor becomes clear that if you are able to increase your cyclone's volumetric capacity (by means of the addition of a barrel section or utilising a bigger diameter cyclone), you will be able to operate the unit at higher medium-to-ore ratios which will have an impact on the amount of misplaced material. The higher medium-to-ore ratio comes at the possible price of lower cut densities, lower efficiencies for smaller particles or a change in cyclone throughput (depending on what measure is incorporated). These are all factors that needs to be taken into consideration before any changes are made to the physical cyclone.

By simulating the washabilities represented by Sample 2 (from the above example), the following comparison was made before and after making the following modifications:

- Bigger cyclone diameter (1000mm to 1150mm)
- Including a barrel in the cyclone configuration
- Increasing the M:O ratio from 3.1:1 to 4:1

Table 3: Results obtained from optimising aspects around the cyclone.

		Base Case	Optimised case
Feed	tph	800	800
Cyclone Diameter	mm	1000	1150
Barrel		No	Yes
M:O ratio		3.1:1	4:1
Near Dense Material	%	25.9%	25.9%
Product yield	%	54.8%	55.4%
Product	tph	438.7	442.8
Product in U/F	%	2.4%	2.1%
Misplaced product	tph	8.80	7.54

As can be seen from the results summarised in the table above, by making the suggested changes, the plant managed to misplace 1.26tph (8.80 – 7.54) less product to the cyclone's underflow. 1.26tph may not seem like much at first, but this amounts to a possible gain in revenue in the order of R26,000 per day.

The second group of measures that can be taken to address the negative impact of near dense material on the cyclone's efficiency has to do with changes to the feed to the cyclone. By blending the feed with the high value of near density material (Sample 2) with feed containing less near density material (Sample 1), the near density material is actually "diluted" and the negative effect on cyclone efficiency is alleviated correspondingly. Applying this rationale to the two washability samples given earlier in this paper and blending them 1:1, before beneficiating them through the original 1000mm cyclone (without a barrel), generates the following results:

Table 4: Results obtained from mixing low and high near density material prior to beneficiation.

		Base Case	**Mixed Sample case**
Feed	tph	800	800
Cyclone Diameter	mm	1000	1000
Barrel		No	No
M:O ratio		3.1:1	3.1:1
Near Dense Material	%	25.9%	6.4%
Product yield	%	54.8%	67.1%
Product	tph	438.7	537.0
Product in U/F	%	2.4%	1.68%
Misplaced product	tph	8.80	4.43

From the table it is clear that mixing the high near dense material with sufficiently lower near dense material has a much bigger effect on the misplaced product than what was achieved by making physical changes around the cyclone. This gives some insights on the importance or "luxury" of having a plant feed blending stockpile in front of the coal processing plant. Mixing of coal ores are however only a viable option if the two (or more) ores have similar cut densities for the required product qualities. If the required cut density for the mixed ore is lower than the required cut density for the ore with the less near dense material (Sample 1 in this case), running at the lower cut density will result in a yield loss from the one portion of the mix (Sample 1). One then has to weigh out the gain in cyclone product from the less misplaced material in the mixed feed versus the loss of cyclone product due to operating at a too low cut density for one portion of the feed.

Combining the two suggested approaches gives even better results, even though it is only slightly better than what was achieved with the mixed sample case.

Table 5: Summary of results obtained after attempts of optimisation.

		Base Case	Optimised case	Mixed Sample case	Optimised, mixed sample case
Feed	tph	800	800	800	800
Cyclone Diameter	mm	1000	1150	1000	1150
Barrel		No	Yes	No	Yes
M:O ratio		3.1:1	4:1	3.1:1	3.9:1
Near Dense Material	%	25.9%	25.9%	6.4%	6.3%
Product yield	%	54.8%	55.4%	67.1%	67.3%
Product	tph	438.7	442.8	537.0	538.4
Product in U/F	%	2.44%	2.11%	1.68%	1.57%
Misplaced product	tph	8.80	7.54	4.43	4.11

Comparing the initial base case with the optimised, mixed sample case, an additional R42,000 can be made every day by incorporating these changes. At the time of doing these calculations, this amount is sufficient to cancel out the effect of a 22% drop in the current coal selling price (API-4).

Although near density material is the single biggest contributor to misplacement in a DMS cyclone, there are also other situations that will contribute to a cyclone's inefficiencies (for both DMS and hydrocyclones). These situations and observations made in the field will be discussed later on in this paper.

THE HYDROCYCLONE'S ROLE IN THE COAL PROCESSING PLANT

Whether it is to deslime, dewater, densify or degritt, the hydrocyclone in a coal plant doesn't necessarily beneficiate the coal as such, but rather assist or improve downstream processes. Without a desliming cyclone in front of the spirals, the spirals won't be able to beneficiate the plant's fines effectively. Much of the plant's water is also recycled from the fines circuit back from the thickener and to the DMS circuit and therefor issues in the fines circuit will correspondingly have a direct impact on the plant's DMS circuit. Keep in mind that the fines can be in the order of 20% (based on the earlier assumption made in the example) of the total feed to the plant and inefficiencies in this circuit will also have a significant impact on the plant's overall yield.

South Africa has about a billion tonnes of discarded thermal-grade coal fines (Enslin, 2017:3). Redick *et al.* (2007) mentions that the South African coal mining industry is currently disposing of about 10 million tons of ultra-fine coal (<150 μm) per year. The quality of these fines is very similar to the Run-of-Mine (ROM) coal qualities and in some cases even better. More and more coal beneficiation plants are starting to wash, add or mix this material with their product since there is still substantial potential energy locked up in these fines. The question arises however whether our plants are first of all running with optimised fines circuits and secondly have enough capacity for the additional fines. With frequent visits to “older generation” coal processing plants washing dump material or weathered coal, it becomes clear that their fines circuit is the bottleneck for their entire process because of capacity constraints. The fines circuit simply wasn’t designed initially to handle much more than 10% fines in the total feed to the plant. Below is a table with design specifications for 4 coal processing plants in the Witbank coalfields proving that they were not designed for fines in the order of 20% of total feed to plant:

Table 6: Design specifications of various plants in the Witbank coalfields.

	Plant 1	Plant 2	Plant 3	Plant 4
FTP [tph]	1010	600	2000	200
Fines [tph]	114	60	133	25
% Fines in FTP	11%	10%	7%	13%

Care should be taken to avoid increasing the feed to the hydrocyclones to such an extent that their efficiency is compromised. For effective operation it is suggested that the %Solids$_{v/v}$ in the feed to the cyclone should be in the order of 10% to 15%. Values more than 15% is still acceptable under certain specific circumstances, but as soon as the %Solids$_{v/v}$ in the feed to the cyclone exceeds 30%, inefficiencies become too high and it is not worthwhile to operate that specific cyclone anymore. Since it isn’t always as easy or quick to determine the %Solids$_{v/v}$ in the feed to the cyclone, the following graph was created to correlate the slurry density (which is much easier to determine onsite) with the %Solids$_{v/v}$ at various solids SG’s. As can be seen from the graph, if you work with a solids SG of 1.55, you can’t really feed a slurry much thicker than 1.08g/cm^3 to a hydrocyclone and still expect sufficient separation.

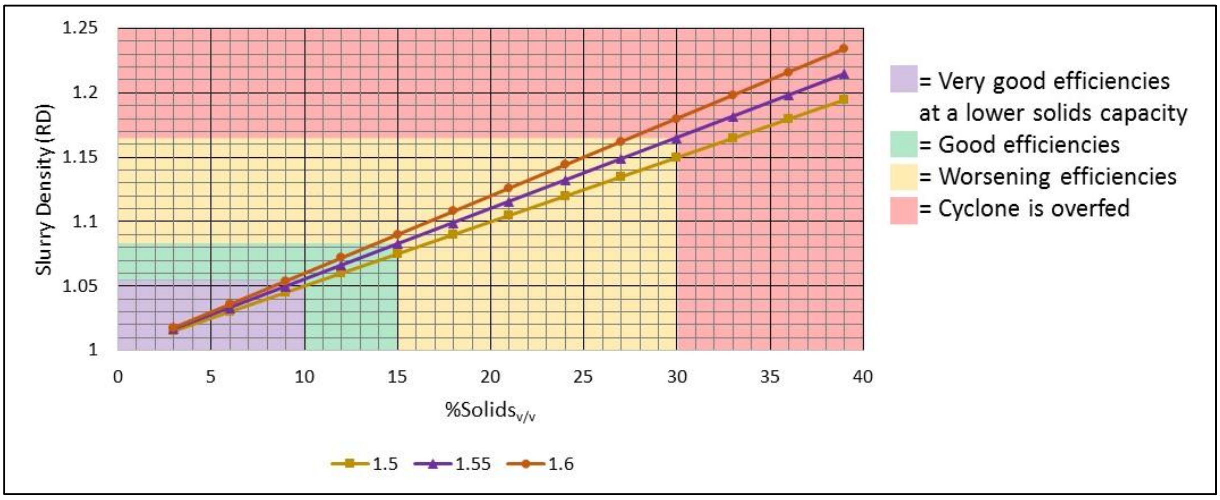

Figure 10: Correlation between %Solids$_{v/v}$ and slurry density in the feed to a cyclone at different solids SG values.

The following scenarios describes the potential consequences of having a fines circuit that doesn't have sufficient capacity for the increase of fines in the feed to the coal processing plant. Scenario 1 is based on a plant with a feed rate of 1000tph, a 70% product yield in the DMS circuit and initially 10% fines in the feed to the plant:

Table 7:Different scenarios depicting the effect of increased % Fines in the feed to plant

		Scenario 1	Scenario 2	Scenario 3
FTP	tph	1000	1000	500
Solids SG	g/cm^3	1.55	1.55	1.55
Fines in FTP	%	10	20	20
Feed to DMS	tph	900	800	400
DMS product yield	%	70	70	70
DMS product	tph	630	560	280
Feed to Fines circuit	tph	100	200	100
Desliming cyclone volumetric capacity	m^3/hr	430	430	430
$\%Solids_{v/v}$ in feed to desliming cyclone	%	15	30	15
Expected desliming cyclone efficiency		Good	Bad	Good

Should the % fines in the feed to the plant increase from 10% to 20% and the feed rate to the plant is kept constant at 1000tph, the $\%Solids_{v/v}$ in the feed to the desliming cyclone will increase from 15% to 30% and the cyclone's efficiency will drop significantly (Scenario 2). This will have a negative impact on the recoveries made by the downstream equipment and the water recycled back to the DMS circuit if the plant's thickener is already operating at its limits. To get the $\%Solids_{v/v}$ in the feed to the desliming cyclone back to an acceptable level, the plant will have to cut back on the total feed to plant and thereby reducing the amount of clean coal produced via the DMS circuit. In this specific (and very extreme) example, if the fines in the feed to the plant was to increase with 10% (from 10% to 20%), the plant would be forced to reduce the total feed to plant to ensure that the fines circuit still runs within operating parameters. The knock-on effect will be a decrease of 56% (from 630tph to 280tph) of the DMS product. Since the biggest portion of the plant's product is produced via the DMS circuit, many plants in this situation would opt to run their fines circuit at a lower efficiency and keep the total feed to plant at a maximum.

COMMON FIELD OBSERVATIONS CAUSING CYCLONE INEFFICIENCIES

The following observations are made on a regular basis in the coal processing plants in the Witbank coalfields. The examples given in this paper will have a negative impact on DMS as well as Hydro-cyclones and should be avoided as far as possible:

- Bends in the feed pipe to the cyclone.

The first prize would be to have a straight pipe feeding into the cyclone (or at least straight for nine pipe diameters right before the cyclone) in an attempt to get close to a laminar flow into the cyclone. If this is not possible at all, the pipe should at least turn in the same direction the material will follow inside the cyclone.

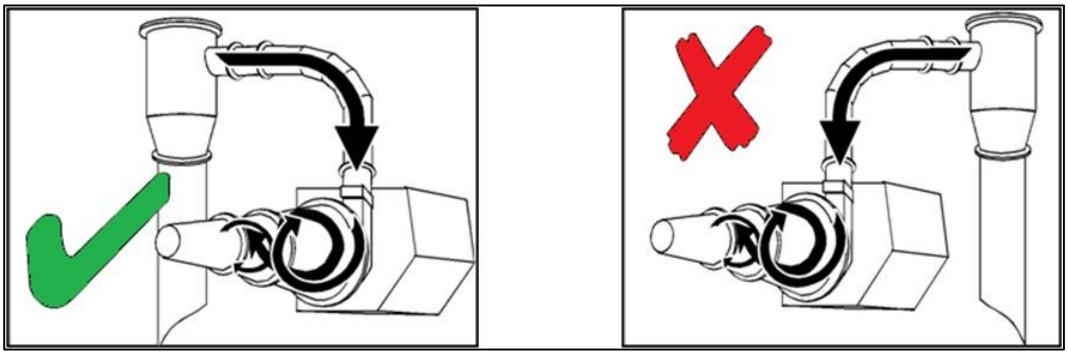

Figure 11: Installation of bends in front of a cyclone.

In the following examples, the bends right before the cyclones' inlets will cause "pre-classification" of the feed particles resulting in unnecessary turbulence and particles being in the wrong positions entering the cyclone. Together with the drop in efficiency, it will also have a negative impact on the expected wear life of the cyclones. Keeping in mind that the residence time for each particle in the cyclone is very limited, situations like these should be avoided at all cost.

Figure 12: Non-optimal installations of bends prior to cyclones.

- "Home-made" feed distributors and manifolds.
  The idea behind a feed distributor is to divide the feed equally between the cyclones with no bias. Should you get this wrong, not only will it influence wear life, but also the product produced by each cyclone. If the cyclones in the same cluster don't get the same feed, you cannot expect them to deliver the same product.

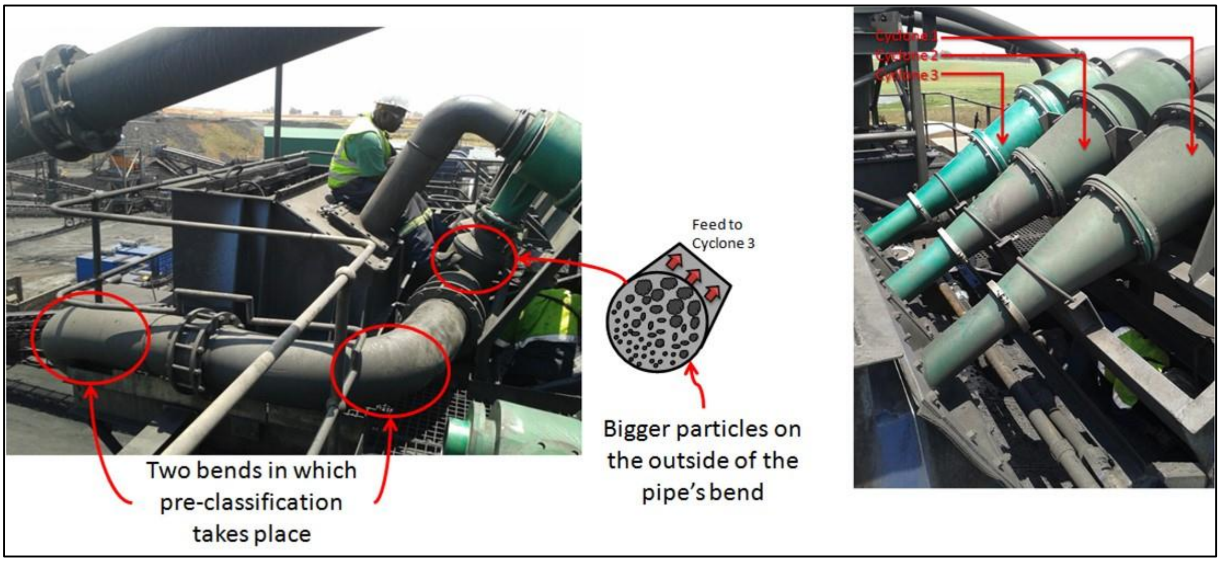

Figure 13: Effect of feeding a cluster of cyclones from a "home-made" manifold.

- Siphoning created in the cyclones' overflows.
  The cyclone's overflow should discharge at atmospheric pressure at a level equal to or higher than the feed inlet. If for instance the overflow discharges at atmospheric pressure at a level far lower than the spigot discharge, a siphon will be created in the overflow and a high misplacement to overflow can be expected. This can be detrimental for equipment, like a thickener, that is very sensitive to oversize particles in the feed and is fed by the overflow from a dewatering or desliming cyclone. If the overflow discharges into a tank or body of water, also ensure that the overflow doesn't discharge below the water level.

Figure 14: Siphoning created by inappropriate overflow installation.

- Cyclone installation angle.
  The installation angle of DMS cyclones is chosen to ensure that the contents of the cyclone drains out when the feed to the cyclone is stopped. Should there be any flat surfaces (relevant to the horizontal), material will build up and may cause blockages during start-up.

Figure 15: Cyclone installation with horizontal surfaces that is prone to cause blockages.

A cyclone with a cone angle of 20^o (typical for a DMS cyclone) will normally then be installed at a 15^o angle.

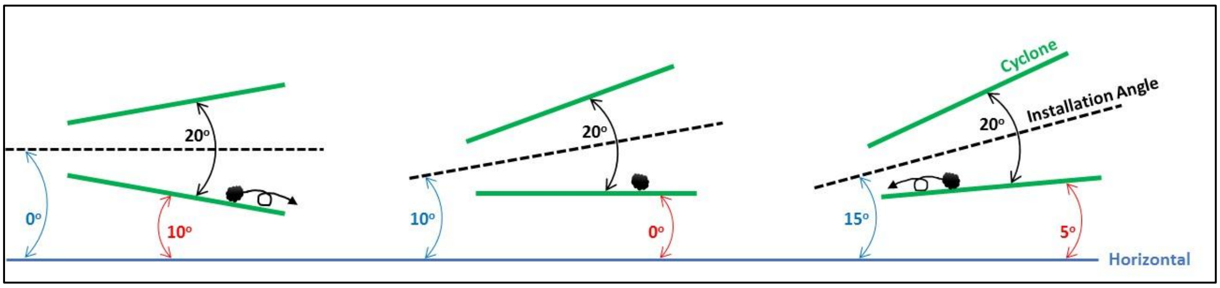

Figure 16: Rationale behind deciding on the installation angle of a cyclone.

- Pipe ID vs. inlet ID
  The cyclone's inlet inner diameter is designed specifically to affect the entering particles' velocity as it enters the cyclone. The inner diameter of the pipe feeding the cyclone therefor shouldn't be smaller than the inner diameter of the cyclone's inlet.

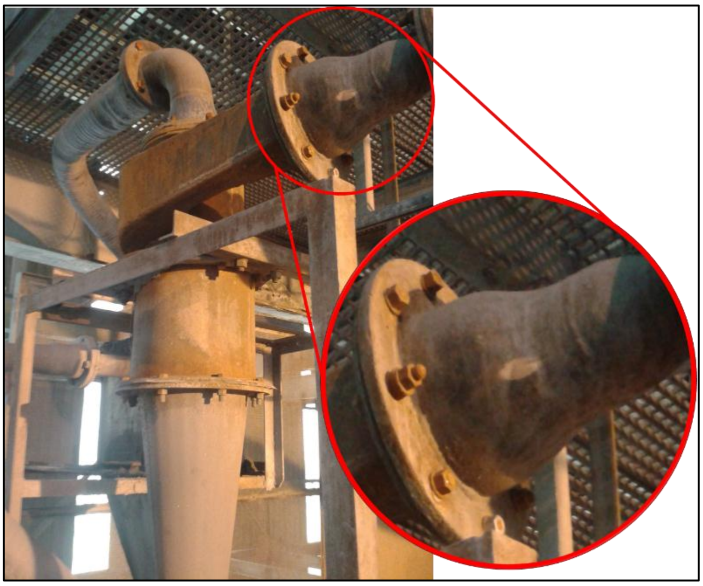

Figure 17: Cyclone feed pipe with a smaller ID than that of the cyclone's inlet.

- Using flexible hoses around the cyclone.
  When flexible hoses are connected to the cyclone, care should be taken to ensure that they are always open and allow free flow of material through them.

Figure 18: Flexible hose blocking free flow of material.

Making sure that your cyclones' physical installation is up to standard is a relative easy way of ensuring that inefficiencies are addressed.

OPERATING CYCLONES EFFICIENTLY FOR LONGER.

Now that it is known how important cyclones are in the coal processing plant and factors that can influence their efficient operation has been addressed, the aim is to keep them in this state for as long as possible. This is the point where maintenance management around the cyclones comes into play.

Normally there are three levels of maintenance that can occur in and around a cyclone in the plant. The very first level is where we react on a certain event – corrective maintenance. This is not ideal since there is only reaction after an event already took place. The time between the event taking place and it being corrected means that there is either no production or poor efficiencies. Nonetheless, for that period of time, the cyclone is not performing at the level it should and time wasted is money lost. This is also commonly referred to as a "break-down" and this is typically when a cyclone is worn through and leaking. Although this is an opportunity for plant personnel to showcase their creativity in patching holes, the cyclone is still not performing optimally and if possible, care needs to be taken to ensure that the plant doesn't operate in this maintenance space.

Figure 19: Patched cyclones in operation.

The second level of maintenance (and this is where OEMs also need to play a big role) has to do with preventing certain catastrophic events from taking place. Here special attention needs to be given to the material of construction of the cyclone (make sure it is ideal for the specific situation) and ensure that the cyclone is operated within the predetermined design specifications. The concept of preventive maintenance requires that the relevant stakeholders monitor facilities, systems and equipment so closely that they know where to look to find small problems before they can become larger, costlier headaches. One also must take care not to go overboard with the preventative maintenance as excessive preventative maintenance will increase the plant's overall maintenance cost. As can be seen from the following graph (TÜVRheinland, 2019) there is an optimal maintenance zone where the plant's total maintenance cost is at a minimum.

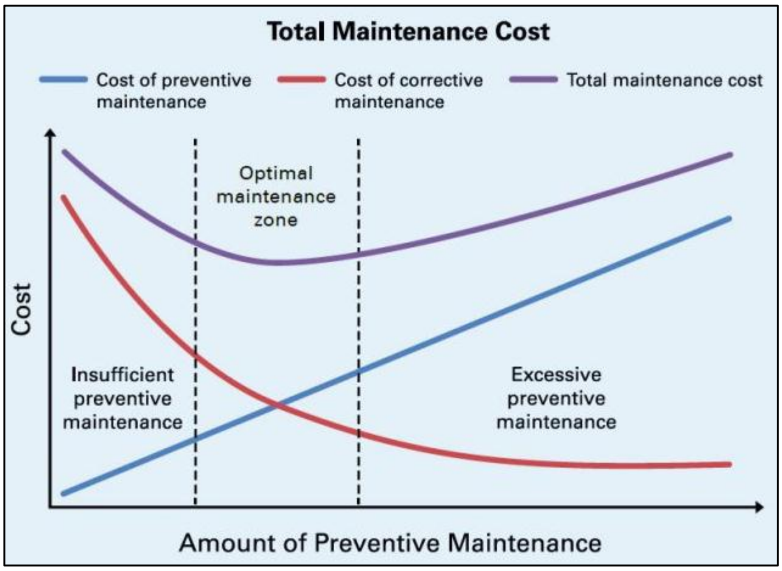

Figure 20: Balance between preventative and corrective maintenance.

The top level of maintenance that one needs to strive to achieve is predictive maintenance. This goes further than preventative maintenance, requiring that the relevant stakeholders know not only where a problem will arise but when, and then take steps to avoid it. Some of the tools that can be used to assist in this regard are:

- Multotec's Green dot tiles.
  The idea behind this concept is to imbed the ceramic tiles used to line cyclones with a green ceramic disk of which the thickness can be predetermined. This side of the tile will then be the side that gets fixed to the cyclone wall. With time, as the tile wears through, the green dot will become visible indicating that the tile is wearing thin. At this stage plans need to be in place to replace the cyclone or that specific part, before the cyclone gets a catastrophic failure. With time one can also build up history to determine what the specific wear rates (mm/month or mm/t) are for the different sections of the cyclone which will allow for better planning.

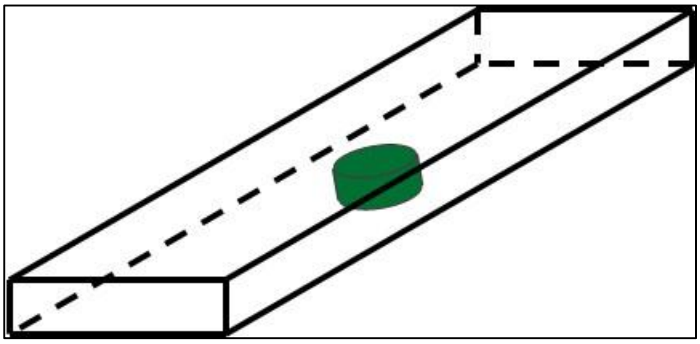

Figure 21: Simplified schematic of Multotec's greendot tile.

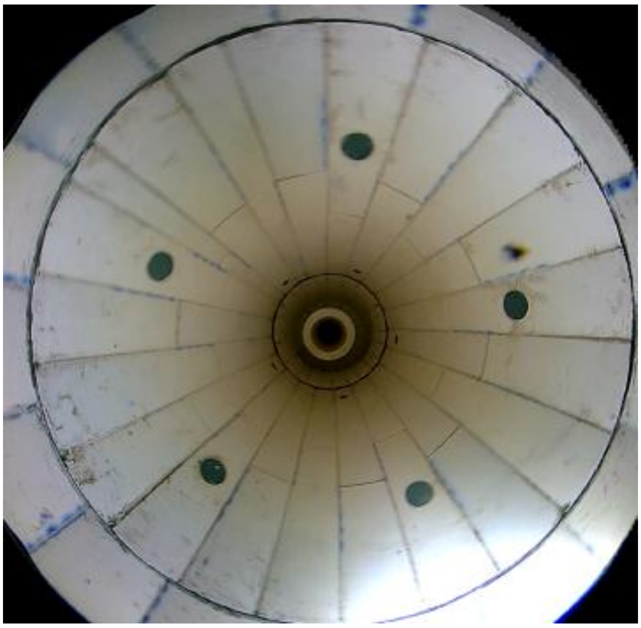

Figure 22: Internal view of a cyclone lined with Multotec's green dot tiles.

- 360^{o} VR inspection camera.
  By inspecting the internal wear surface of a cyclone with this camera, detailed reports can be generated, and problem areas can be identified and addressed before corrective maintenance will be required. Below is an example of the type of information that can be generated with this tool:

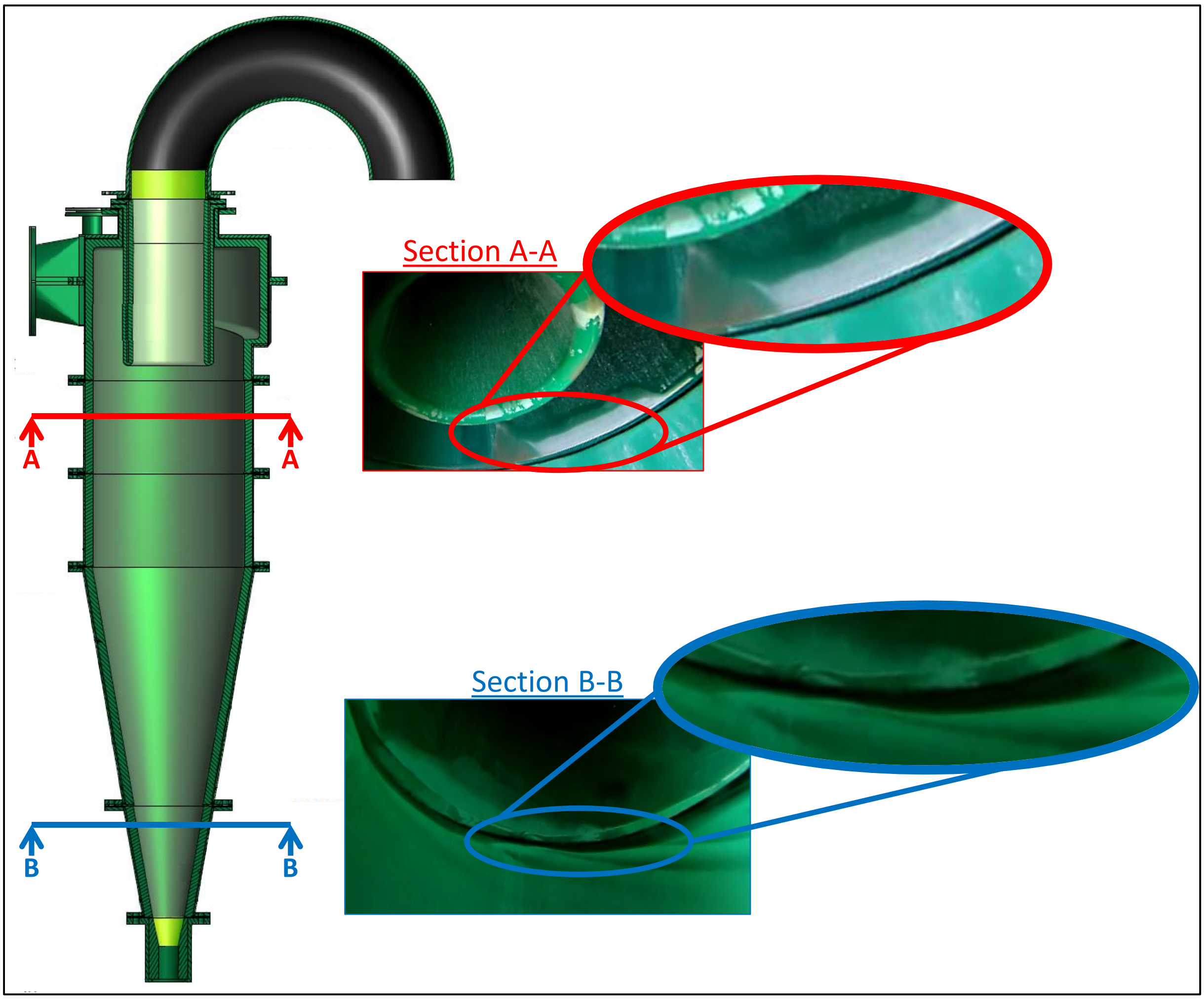

Figure 23: Internal inspection of a cyclone.

CONCLUSION

Cyclones are without a doubt at the heart of any coal processing plant. With lots of time and money invested in developing them to what we have today, they make a significant contribution to a plant's overall economic performance. Being a stationary piece of equipment with no moving parts, they are quite easy to maintain and keep at a satisfactory operating level. Even though more and more plants in South Africa need to beneficiate low grade coal reserves and the current coal prices are on a downward spiral, looking after the cyclones in the plant will ensure that they look after your bottom line.

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