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Abstract for Coal Prep. Congress,

Title: A CYCLONE FOR A REASON – Dense Medium Cyclone efficiency.

Cyclones have been in mineral processing since the first patent in 1912 and amongst the many uses of the configuration of the cyclones is the DENSE MEDIUM CYCLONE, used for separation of particles of different densities; separation enhanced by the use of either magnetite or ferrosilicon as an essential element of the process to create the desired effect.

The MULTOTEC dense medium cyclone has been successfully applied in, primarily, coal washing but also in hard rock beneficiation, specifically diamonds, iron ore and platinum, to enhance and improve the overall process resulting in improved revenues for the user-plant.

The initial ratios between the various components making up the dense medium cyclone (DMC) were developed by the Dutch State Mines Research Institute and still apply today. Thus DMC may be said to be "old technology" but improvements in materials of construction (linings, patterns), methodology of manufacture and vital ancillary components (pumps, vibrating screens and magnetic separators) have enabled the technology to be applied in different configurations worldwide at higher capacities with improved life cycles and efficiencies.

This paper will briefly describe some of MULTOTEC's experiences and applications of DMC in coal, specifically touching on "high density cut points" in coal and detail some current successful experiences in coal plants.

The paper will include technical data comparing proposed performance parameters with actual results from operating plant and conclusions to be drawn from the data.

Key words: dense medium, cyclones, process, coal washing, high density, yield, clean coal, ash.

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Introduction

The patent for a hydrocyclone registered in 1912 and the cyclone has been evolving ever since. Initially the unit was very much simpler design but it certainly provided a quantum leap in process technology and enabled improvements in following years.

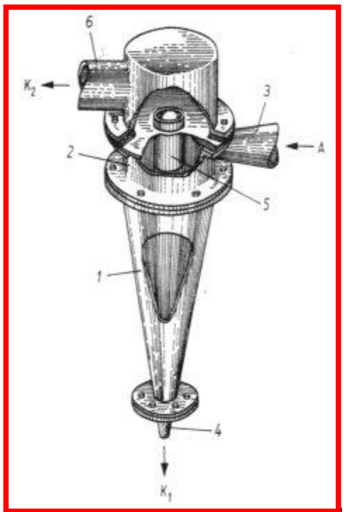


Fig 1
CYCLONE PATENT

In the mid-1940's the Dutch State Mines (DSM hereafter) identified that cyclones had potential use for the separation of coal/ash and subsequent research established the various ratios between

- inlet opening : inlet head diameter : vortex finder diameter : spigot diameter that gave the optimal efficiency of separation.

Research also showed that, for coal processing, magnetite is the favoured dense medium, which, added to the water, creates slurry of suitable capability to separate sinks (ash) and floats (coal).

In South African research in 1950 by the then Fuel Research Institute of South Africa, tests concluded that led to the application of dense medium cyclones in coal processing. For South Africa this meant the first thermal coal washing using dense medium cyclones began in the Witbank Coalfields.

Power station feed coal has increasingly come under the microscope as environmentalists query the emissions. Not only that, but increasing attention is paid to the quality of the coal burned specifically ash content because, in both South Africa and India, coal is transported over long distances which causes road deterioration. Further, costs of electric energy, driven by increasing demand, dictates that power stations be more diligent about the quality of coal received from suppliers.

There are many benefits to using washed coal in power plants including:

- Consistent power plant performance and improved thermal efficiency
- Reduced ash handling
- Reduced emission issues
- Lower maintenance resulting from coal's lower wear characteristics than "stone"

For the country, washed coal results in:

- Less road damage from transportation of "stone"
- Cleaner air
- Better power generation costs
- Better coal reserve utilization through more efficient lower grade reserve exploitation.

As with all good things, there is a downside and that is that the coal washeries have a more complicated process with potentially higher costs unless due diligence is applied to process and resultant equipment selection.

Thus more efficient process systems were sought to produce clean coal.

Early observations

Once the efficacy of Dense Medium Cyclones (DM) was established and cyclone washing of coal was put into practice certain limitations raised their ugly heads.

The established ratios of inlet throat : inlet head diameter : volumetric capacity of DM cyclone : vortex finder : spigot and the considered best ratio between medium and ore of 3.5:1.0 meant that DM cyclones had to be manufactured in specific proportions.

This size limitation also dictated the largest size of coal that could be fed because there is a direct relationship between inlet throat size and coal lump size beyond which the cyclone will choke.

Similarly, the inlet diameter, which is also proportional to the inlet throat, determines the volumetric capacity of the cyclone, and therefore effective throughput of solids because, following the rules developed for best separation, the ratios of medium to ore should be a minimum of 3.5:1.0 for proper washing and separation of the coal.

Cyclone configurations.

In the early phases, the DM cyclones were made of cast iron with high chrome and nickel content. Castings were favoured technology because manufacturers had been able and competent at using this methodology for some years.

The high chrome and nickel were added as a wear resisting element ensuring that the cyclones lasted some time rather than requiring continuous maintenance and spares replacement and inventory.

The downside of this manufacturing method is that the maximum size of cyclone was limited by the mould required to make the unit and the handling capability of the foundry.

Thus, initially, DM cyclones were at a maximum size of 710 mm inlet head and capacity of the order of 100 tph of raw coal feed, maximum lump size approx 50 - 60 mm.

Consequentially, coal washeries therefore needed a combination of technologies to wash the coal from 150 or 80 mm down. Flowsheets were seen to include drum washers like the Teska, Wemco, Norwald and so on for the plus 10 to 20 mm coal, and the less-than-that size in DM cyclones. Fines below 2.0 mm presented further issues like simple, cost-effective separating equipment, dewatering operating cost constraints vs. clean coal returns.

Focusing on cyclones, we turn to the Grootegeluk Colliery in South Africa. This mine has the largest coal output in South Africa and probably the southern hemisphere. Accordingly, any efficiency implemented on the plant has high value returns.

Operational considerations

Initially, large size coal (150 x 28 mm) was washed in drums mainly because there is no limitation on the feed inlet. Cyclones of the day had a small feed inlet (20% of inlet head diameter by DSM rule) which resulted in choking if the 1:3 ratio of throat area : top size was not followed.

This meant that the secondary beneficiation at Grootegeluk was carried out in multiple modules each equipped with 4 x 510 mm cyclones because of the high throughputs required by high plant output to power station.

Fig 2
4 x 510mm DM cyclones
Grootegeluk [6]

Distribution was identified as another crucial element of good performance, especially as the cyclones were gravity fed (for wear considerations).

With due consideration being given to the conditions, a decision was taken to replace the 4 cyclones with one larger 810 mm unit; pump-fed because of higher pressure needed but essentially replacing each module of 4 with 1 unit. Tests would also be conducted on efficiencies with and without the barrel. [4]

The results speak for themselves and the supplier now had to take the step towards manufacture of larger diameter cyclones.

Parameter	Reference module	Test 1	Test 2
NAME	4 X 510mm	1 X 800mm	1 X 800mm + Barrel
FEED RATE	125t/h	135t/h	135t/h
M:C	4	4.2	4.2
EPM	0.020	0.015	0.021
SG50	1.373	1.382	1.366
EPM/SG50	0.0146	0.0109	0.0154

Fig 3
Cyclones results comparison, Grootegeluk [4]

The barrel did not, in these tests, substantially improve performance.

Improved configurations

Simultaneously, attention was being given by cyclone manufacturers to the cyclone's configuration, methods of manufacture and materials of construction.

Early cyclones followed the initial inlet head configuration and were tangential to the main separating zone in the inlet head. This created turbulence, which resulted in high wearing areas but more critically interfered with the efficient separation of coal product and discards.

Larger DM cyclones were being considered but the limitation of cost caused by large castings prescribed against these larger cyclones – an alternative needed to be found.

Developmental work followed and the subsequent cyclones progressed through involute entry on 90° to evolute entry on 180° (Fig 4) to the current scrolled evolute entry (Fig 5) which has an arguably 35% improvement on the initial tangential capacity and a higher efficiency.

The scrolled entry has an efficiency effect that begins the downward reporting of high density material immediately on entry and therefore improves separation efficiency in the DM cyclone.

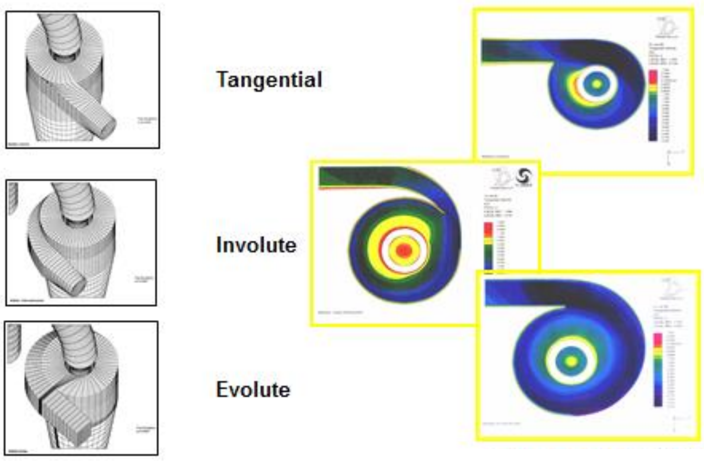


Fig 4
INLET HEAD CONFIGURATIONS

Materials of construction

The general use of improved wear resistant linings was also on the upswing at this time and DM cyclones were no exception.

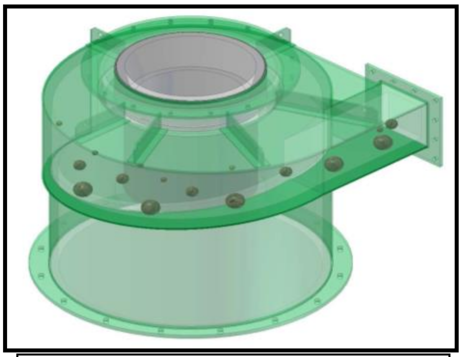


Fig 5
SCROLLED EVOLUTE INLET

Ceramic-filled epoxies had made their entry, as had dense alumina (Al_2O_3) ceramics and with the advent of tiles as a lining material, the manufacture of DM cyclones changed.

Now the units were made from fabricated mild steel shells with ceramic linings, installed in increasingly improved patterns e.g. staggered horizontal joints to prevent fine slurry attacking the epoxy adhesive; tapered and angled cone tiles for smoother surfaces, improved wear life and less turbulence.

The ceramic tiles now allowed manufacture of larger diameter DM cyclones, especially as larger pump sizes and greater screen widths were now becoming available from leading equipment suppliers.

The advent of the large diameter, high capacity, very efficient dense medium cyclone was at hand.

Essential ancilliaries.

Together with dense medium separation comes a host of support equipment without which the DM cyclone or even the drum, cannot function. These relate to primary classification and desliming, washing and recovery of medium, pumping and naturally drying.

In the early stages of dense medium coal washing, pumps had not yet been developed to match high volumes of slurry, screens for washing and recovery of medium (drain & rinse screens) were limited in width and therefore capacity and, crucially, distributors for feeding multiple smaller cyclones were inefficient.

Increasing the sizes of all this equipment now enabled a look at larger diameter DM cyclones and the trend became a rush.

The DSM rules still applied however, so the larger cyclones still required the same minimum medium to ore ratios, still required all the ratios between components but now, with the larger throat the cyclone could digest a larger top size of coal (the Multotec 1450 mm cyclone is suitable up to 95 or maximum 100 mm coal).

Large diameter DM cyclones

The sizes of the cyclones now proceeded to grow through 1000 to 1150, 1300 and even the monster, 1450 mm. These sizes were to have their own challenges however, as South African studies showed a new phenomenon, the so-called "breakaway size". This hypothesizes that the large diameter cyclones are less efficient at washing coal from 10 mm down and that the plant should be split into two fractions:

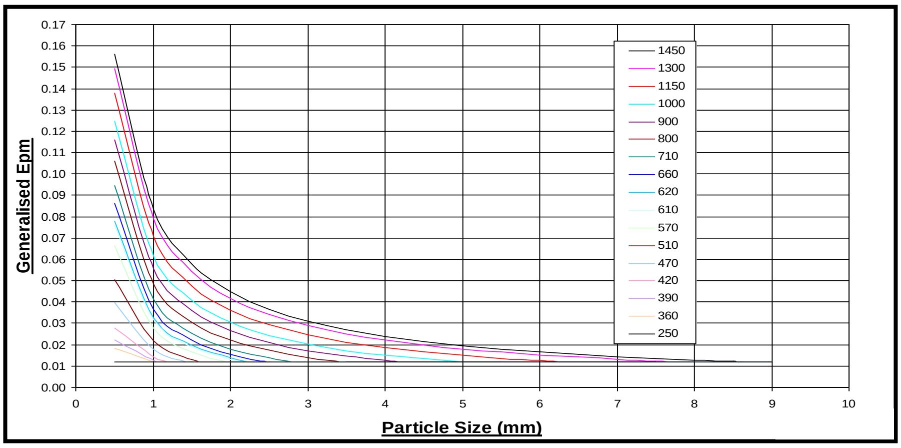


Fig 6
Cyclone efficiency curves

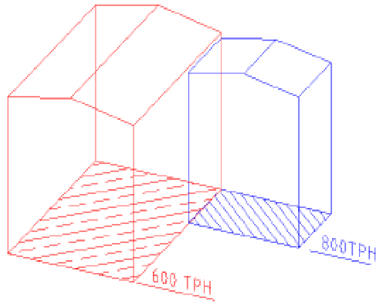
- large coal (plus 10 – 15 mm but less than 95 – 100 mm) and

- fine coal below 10 or 15 mm but above 1.5 or 2.0 mm (the threshold of efficient medium removal/recovery, of dewatering ability and of clean coal to cost efficient return)

Despite the Australians showing that the breakaway size had limited affect in their washeries (Fig 7) [5], the South African investigations showed a definitive improvement in a split process and further that the use of spirals on the -1.5 or 2.0 to plus 100 µm fractions, flotation on the extremely fine coal, produced high yielding plants that are more cost effective (Fig 8). [6 & 7]

	Goonyella		Riverside	
	Twin	Single	Twin	Single
	710mm	1m	710mm	1m
Pressure(cyclone diameters)	10	11	10	10
Size Fraction	Probable Error			
+16	0.028	0.025	0.020	0.014
-16+ 4	0.030	0.026	0.025	0.020
-4 + 2	0.038	0.028	0.045	0.026
-2 + 0.5 (ww)	0.055	0.045	0.070	0.049

Fig 7
Ep comparison
710 vs. 1000 mm DM cyclones



Structural Volume as a Function of the Feed Capacity

Fig 8
Capacity

The benefits according to the Australians regarding plant footprint, individual module size vs. throughput, plant operator numbers, maintenance and a host of other things, far outweighed the potential inefficiency losses when Australian coal is considered (Fig 7) [5].

However, South Africa begs to differ and thus still looks to a split flowsheet for best practice.

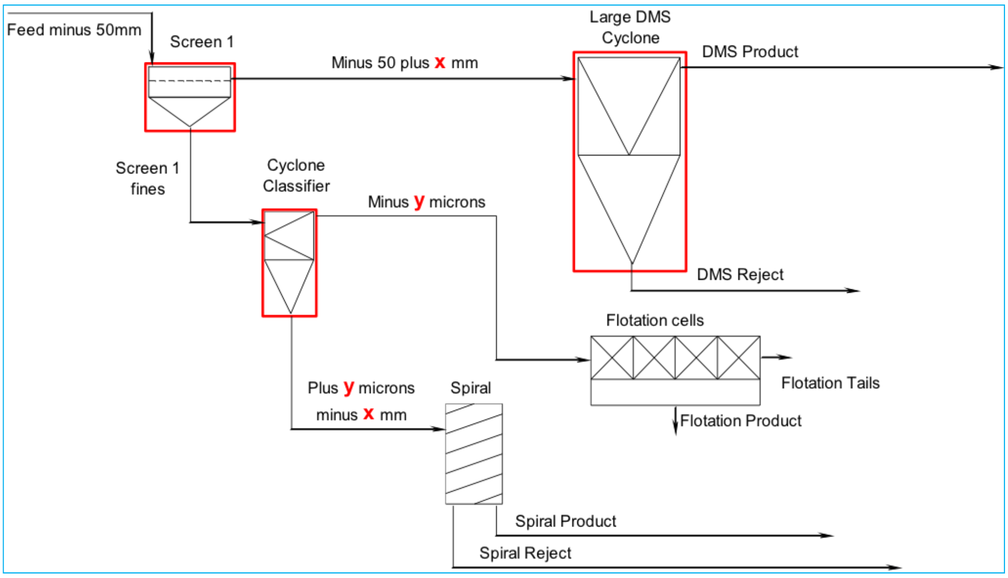


Fig 9
Split process
flowsheet

In the background, the question is still being investigated of high density cuts giving best returns for power station feed-coal.

Grootegeluk had investigated the cut density as early as November 2009 and in a paper presented to the South African Coal Processing Society technical meeting [2], the vexaceous issue of washing at densities of 2.0 and above was examined.

The reason for this is that ESKOM (South Africa's power utility) required a 35% ash product for its Matimba Power Station and this could be washed from all benches of the Grootegeluk quarry at a density of > 2.0 with an acceptable yield (for power station coal) of 47%. Thus the investigation detailed how this difficult to achieve but possible to achieve target was reached.

The conclusion delivered in the paper [2] is high density cuts are possible with existing DM cyclone configurations (both large and small diameter) if:

- densifiers are the key for producing correct medium at 2.3
- the dilute circuit must have sufficient capacity to control magnetite consumption
- ceramic cyclones have the best life/cost performance

The benefits are:

- magnetite consumption does increase at high densities but are insignificant when compared to improved plant yield
- densities of 2.05 are achievable with standard grade magnetite (85% < 45 µm)

Cyclone diameter (mm)	Plant	Feed size	Average particle size of feed	d50*	EPM*	Imperfection*
1450	Newlands[6]	50 x 8	29.0	1.644	0.0170	0.0103
		8 x 4	6.0	1.647	0.0262	0.0159
		4 x 2	3.0	1.676	0.0353	0.0211
1500	Benga[7]	50x4	27.0	1.628	0.0114	0.0070
		4x1.2	2.6	1.704	0.0528	0.0310
1300	Benga[7]	50x4	27.0	1.390	0.0121	0.0087
		4x1.2	2.6	1.417	0.0280	0.0198
1500	Drayton[8]	50x31.5	40.8	1.575	0.0160	0.0102
	Test 1: Aug 2005	31.5x8.0	19.8	1.581	0.0210	0.0133
		8 x 1.0	4.5	1.580	0.0300	0.0190
1500	Drayton[8]	50x31.5	40.8	1.615	0.0200	0.0124
	Test 2: Aug 2005	31.5x8.0	19.8	1.600	0.0140	0.0088
		8 x 1.0	4.5	1.600	0.0350	0.0219
1500	Drayton[8]	50 x 16	33.0	1.690	0.0130	0.0077
	Test 3: Aug 2006	16 x 8	12.0	1.725	0.0200	0.0116
		8 x 4	6.0	1.690	0.0280	0.0166
		4 x 1.4	2.7	1.700	0.0300	0.0176

Fig 8
DM cyclone results [7]

Conclusion

The design, configuration and materials of construction used in the modern day MAX dense medium cyclones is true to the original DSM concepts but with necessary upgrades and modernization.

The use of large diameter cyclones with the concomitant benefits is here to stay but should be applied with a diligent eye on the type of coal.

Finally, high density cuts are possible, have their place and definitely improve overall plant yield.

References

1. Breedt, F, Grootegeluk Colliery – High density washing at Grootegeluk Coal Mine
2. Bosman, J, PESCO, South Africa – Dense medium drums – sizing and selection
3. de Korte, GJ, CSIR, South Africa - High density processing of coal
4. de Korte, GJ, CSIR, South Africa – A review of dense medium cyclone performance
5. de Korte, GJ, CSIR, South Africa – Should coarse and small coal be processed separately?
6. Honaker, Davis, Hollis, USA – Large diameter DMC performances in U.S. preparation plants
7. Mackay, Hoffman, Clarkson, Mitchell, Sedgeman Australia – The use of large diameter cyclones
8. Naylor, M, Parnaby UK – Correspondence regarding high density anthracite washing in Ukraine.
9. Steyn, HG, Grootegeluk Colliery – Large diameter cyclones vs. multiple cyclones
10. Sharpe, M, Sharpe International – Coal preparation “a discussion on conventional and advanced technology” at Coal Peparation workshop, India
11. Spath, Mann, Kerr, N.R.E.L., Colorado, U.S.A. - Life cycle assessment of coal-fired power production
12. U.S.A. Bureau of mines – Rport 7154, performance characteristics of coal-washing equipment.
13. Wilkes, K, Dorr-Oliver Eimco UK – The practical application of the WEMCO HMS drum separator in the mining & metals recovery industries
14. Wilkes, K, FLSmidth Minerals – Development and recent application of WEMCO HMS and flotation cells
15. Zamuda, CD, U.S. Department of Energy – A case for enhanced use of clean coal in India: an essential step towards energy security and environmental protection