Performance of a laminar spiral inlet cyclone in a diamond DMS application

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Dense medium separation is applied to the preconcentration of minerals. It is the simplest of all gravity processes and is a technology that can be applied to any ore in which, after undergoing several crushing and scrubbing processes, there is enough difference in specific gravity between the particles to separate product from gangue material.

The major development in DMS cyclone technology *post* the publishing of the DSM Handbook has been based on increasing the capacities of the units (Singleton, 2013). These developments include larger diameter cyclones, and bigger inlet head and vortex finder sizes. The interpretation of cyclone efficiency to date is still based largely on the DSM guidelines (Singleton, 2013).

Because Cavex® is well proven in hard rock mining and coal classification, it was used as a basis for the development of a DM cyclone. Individual casting moulds/patterns were developed and produced in order to fabricate a Cavex DM Hard chrome cyclone with the exact laminar spiral feed chamber that exists when moulded out of rubber (Singleton, 2013). The 400CVXA20 cyclones were supplied to a diamond operation, installed, and commissioned. Using the basic operating principles of DMS cyclones, the predicted results were achieved. There is a definite benefit in focusing on metallurgical efficiency in conjunction with wear properties, rather than equipment life (wear life) as the only parameter during equipment fabrication (Singleton, 2013).

INTRODUCTION

DMS Background

Dense medium separation (DMS) is a form of gravity concentration technology that has historically been used predominantly in the coal and diamond processing industries (Legault-Seguin, Mohns, C. and Rylatt, 2016). This technology is the simplest of all gravity processes and has long been a standard laboratory method for separating minerals of different specific gravities (Wills, 2006).

The DMS process is the primary method used in the diamond industry for the concentration of diamond-bearing ore. Maximum rejection of lower density ore is essential in order to reduce downstream equipment requirements and operating costs, while maintaining required efficiencies (Rodel and Roode, n.d.).

Efficiency Monitoring

As noted by Rodel and Roode (n.d.), separation efficiency comprises a number of variables, such as recovery, proportion of concentrate, and proportion of misplaced material. As it is not easy to measure some of these parameters quickly and accurately, there is a requirement for other, indirect criteria that must be selected to represent separation efficiency, by which the process can then be controlled. The measured or inferred inefficiencies can either be due to diamond losses or due to a high percentage of misplaced float material present in the concentrate (Rodel and Roode, n.d.). It is important to achieve optimum efficiencies without compromising diamond recovery.

The method used on diamond plants to collect data to monitor efficiency is the tracer test. A tracer test is an instantaneous method of determining separation efficiency. The tracer test can provide the operator with an only approximate indication of the separation characteristics and is usually conducted with density tracers. A full tracer test encompasses a test with density tracers varying in density from 2.9 t/m^3 to 3.5 t/m^3, which is close to the density of diamond. (Rodel and Roode, n.d.).

Partition (Tromp) Curve

The efficiency of separation can be represented by the slope of a partition or Tromp curve (Wills, 2006). This is an empirical curve that describes the probability of a particle, on the basis of density, reporting to the underflow (Bosman, 2008). Figure 1 illustrates the partition curve. From this curve the $d50$ and the Ep values are determined.

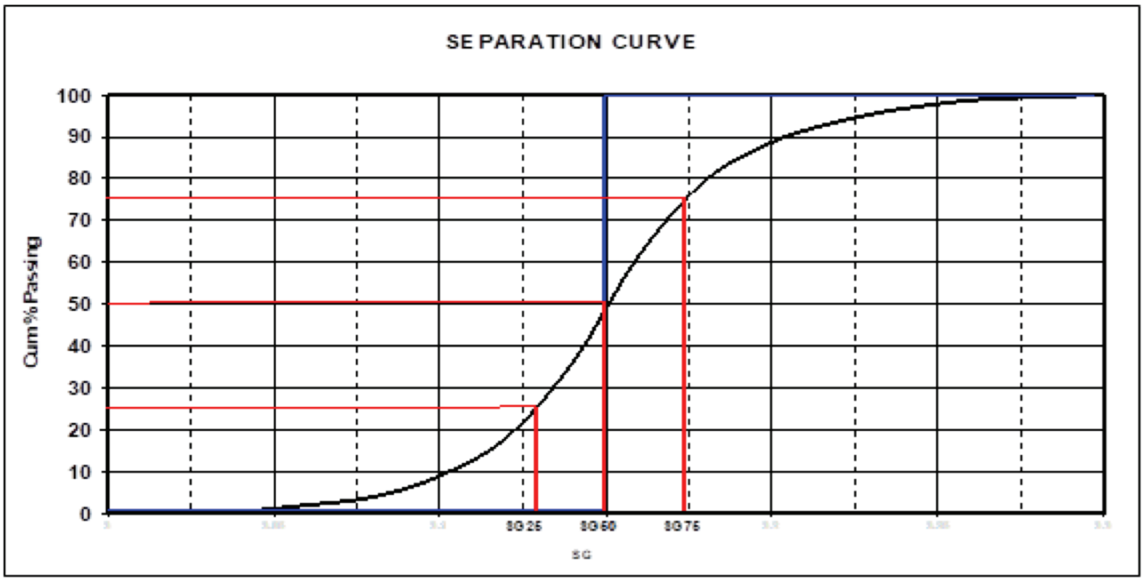

Figure 1. Partition curve.

Many partition curves give a reasonable straight-line relationship between the distribution of 25% and 75%, and the slope of the line between these distributions is used to show the efficiency of the process. The probable error of separation or the Ecart probable (Ep) is defined as half the difference between the density where 75% is recovered to sinks and that at which 25% is recovered to sinks (Wills, 2006):

$$Ep = \frac{d75 - d25}{2}$$

The density at which 50% of the particles report to sinks is shown as the effective density of separation (Wills, 2006). This is commonly referred to as the $d50$.

The lower the *Ep*, the nearer to vertical is the line between 25 and 75% and the more efficient the separation. An ideal separation has a vertical line with an *Ep* = 0 whereas in practice the *Ep* usually lies in the range 0.01–0.10.

Feed Chamber Design

The cut-point is controlled mainly by the cyclone design variables, such as the inlet type and geometry, the vortex finder, and apex openings. The inlet is normally tangential, but involuted feed entries are also common as they are said to minimize turbulence and reduce wear (Wills, 2006). An alternative is the 360° scroll laminar spiral inlet. The understanding of the physics of the internal hydrocyclone flow motion has helped Weir Minerals Group designers to improve hydrocyclone geometry (Singleton, 2013). The laminar spiral inlet head design reduces turbulence and improves the use of the fluid kinetic energy at the hydrocyclone entrance.

Cavex CVXA Hard Metal Cyclones

The Cavex CVXA cyclones are used in (DMS) plants as the main concentration unit, media recovery, as well as for media densification in coal, diamond, iron ore, and andalusite applications throughout Africa. These cyclones are hard-wearing and are cast in 27% chromium iron for maximum abrasion resistance and cost-effectiveness. The components are designed for ease of maintenance, with all surfaces being joined with a layer of epoxy cement.

The Cavex CVX dense medium cyclone features a unique laminar spiral inlet geometry designed to deliver sharper separation, maximum capacity, and longer wear life than conventional involute or tangential feed inlet designs. This design provides a natural flow path into the cyclone body, thereby allowing the feed stream to blend smoothly with the rotating slurry inside the chamber. The result is greatly reduced turbulence through the whole cyclone, thus improving separation efficiency.

Figure 2 is a comparison of flow profiles and wear patterns of a cyclone with a spiral inlet and conventional dense media cyclones with tangential or involute inlet.

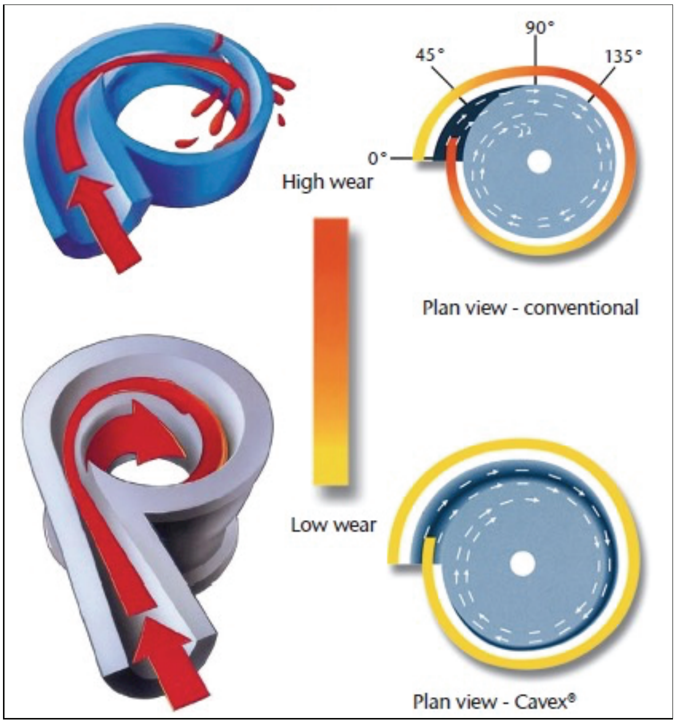

Figure 2. Laminar spiral inlet vs conventional inlet.

The design philosophy is based on increasing separation efficiency by minimizing turbulence inside the cyclone. The reduction in turbulence results in improved separation efficiency and reduced misplaced materials to both sinks and floats in a CVX cyclone. This reduction in turbulence is achieved through the following:

- Combined cone and spigot components in the hard metal range
- Cavex inlet design with 360° scroll. This design was proven through extensive CFD analysis and also multiple installations to date
- Ongoing research and development on methods used to minimize turbulence on assembled ceramic tiled components.

The Cavex CVXA cyclones are designed with a variety of inlet sizes to accommodate a wide top size at specified medium to ore ratios. The inlet sizes range from 0.2–0.33 as a function of cyclone diameter. The Cavex CVX cyclone also has a wide range of vortex finder sizes to maintain separation efficiency at different operating yields and spigot sizes. The vortex finder sizes range from 0.4 to 0.5 as a function of cyclone diameter, and are designed to maintain a strong air-core at different spigot sizes. Spigot sizes range from normal to extra high capacity to accommodate low-yield ores.

The cyclones can also be manufactured with different materials to prolong cyclone life and efficiency. Cavex CVXA cyclones can be fitted with an extended barrel designed for difficult-to-separate ores. The extended barrel increases efficiency by increasing the residence time in the cyclone, especially for ores with a high content of near-density materials.

Lower Total Cost of Ownership

Weir Minerals is focused on supplying best-in-class technology. This includes superior cyclone performance, as well as components that offer lower wear rates. This is achieved by using a combination of materials with different wear rates in different parts of the cyclone. The benefits of this approach are:

- Optimal life of the cyclone in operation
- Reduced maintenance costs by replacing worn cyclone parts *in situ*
- Eliminating the risk of adverse effects on performance by mixing old and new cyclone components
- Reducing safety risk by minimizing the maintenance work on installed cyclones.

(Weir Minerals Dense Medium Cyclone Brochure, 2014).

CASE STUDY – CAVEX IN A DIAMOND DMS APPLICATION

Weir Minerals supplied 400CVXA20 hard metal (27% chrome) cyclones to be operated in a diamond dense medium separation (DMS) application.
The cyclones were expected to achieve the following minimum key performance indicators:

- Wear life of not less than 6 months
  EPM of not greater than 0.08 at a cut density of 3.1 t/m^3.

The cyclones were continuously monitored and a record kept of the frequency of daily operation of the cyclones. This record was made available to Weir Minerals Africa. Free access was provided to Weir Minerals Africa to monitor performance during operation of the two cyclones.

Commissioning and Monitoring Activities

The cyclones were installed in the last week of October 2016 and were commissioned to treat only fines, -8+1mm material (Figure 3).

Figure 3. Cavex installation.

During the course of 2017, the client decided to run a combined DMS, after which the full DMS size range, -20+1mm was treated through all the fines DMS cyclones.

Three visits were conducted by Weir process personnel during operation of the cyclones.

- Visit 1 – October 2016: An initial visit was conducted in order to ensure correct installation of the Cavex cyclones and to address any issues experienced during the commissioning stages.
- Visit 2 – September 2017: A second visit was conducted in order to determine wear on the cyclones by means of a thickness gauge. The client had indicated that the cyclones would have been due for replacement soon after this visit as they were due to reach the maximum tonnage used as a standard for cyclone replacement. It was decided to run the cyclone for an additional 2 months.
- Visit 3 – December 2017: A last visit was initiated to advise the client on further operation of the Cavex cyclones as they had surpassed the expected life.

Tracer Test Results

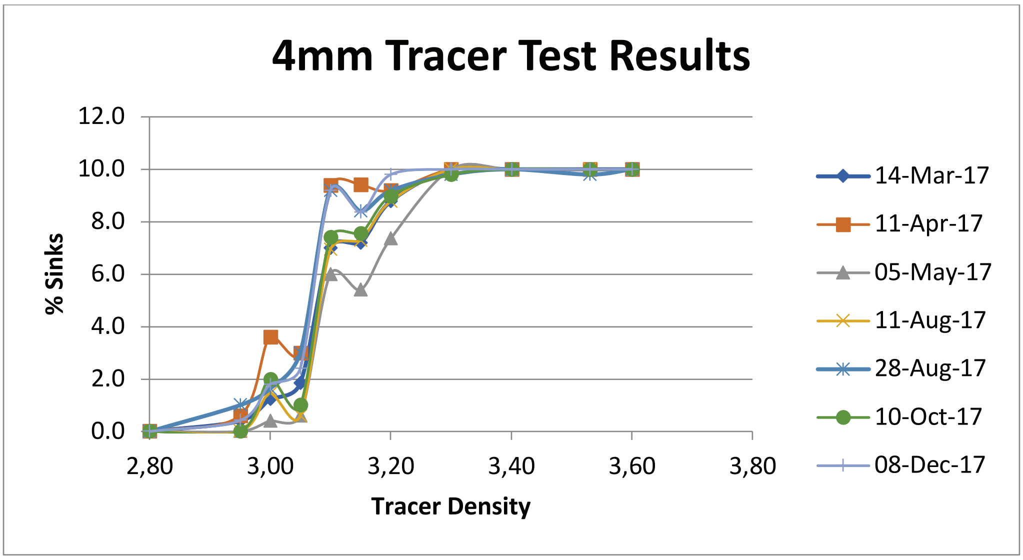

Figure 4. Tracer test results – 4 mm tracers.

Figure 4 and Table I below indicate an average *d*50 of 3.08 t/m3 and within the client expected performance for the 4 mm tracers. The average *Ep* achieved over the operation period is 0.04 and indicates better separation efficiency than the client specification of a maximum *Ep* of 0.08.

Figure 5 and Table I below indicate an average *d*50 of 3.08 t/m^3 and within the client expected performance for the 8 mm tracers. The average *Ep* achieved over the operation period is 0.035, and similarly to the 4 mm tracer test, indicating better separation efficiency. The *Ep* is again well within the client specification of a maximum *Ep* of 0.08.

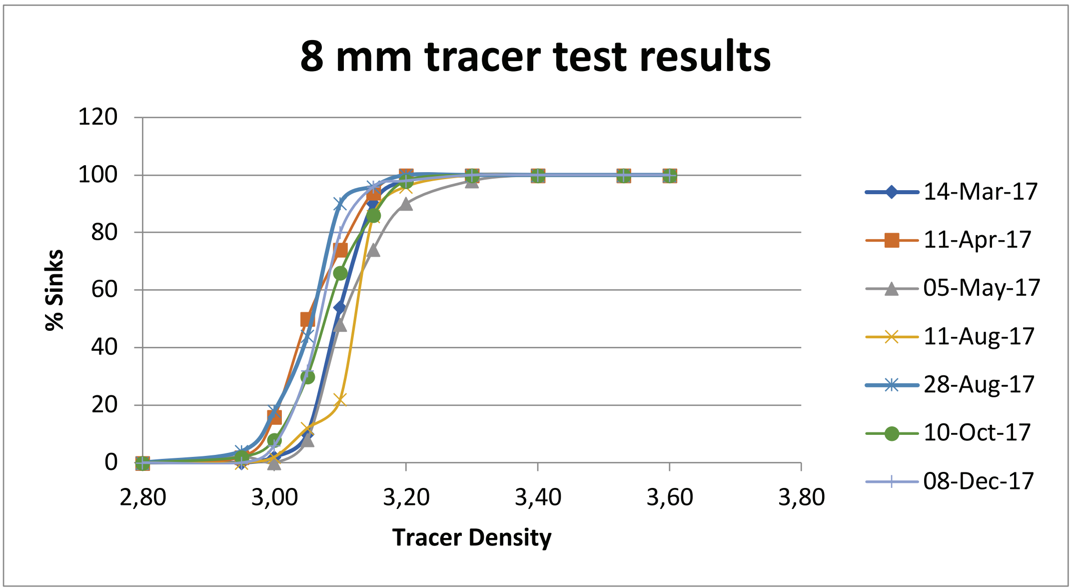

Figure 5. Tracer test results – 8 mm tracers.

Table I. Tracer test results – 4 mm and 8mm tracers

Test Date		d50	Ep		d50	Ep
14-Mar-17	4mm	3.08	0.052	8mm	3.10	0.031
11-Apr-17		3.07	0.052		3.05	0.045
05-May-17		3.09	0.069		3.10	0.041
11-Aug-17		3.09	0.046		3.12	0.020
28-Aug-17		3.07	0.027		3.06	0.035
10-Oct-17		3.08	0.036		3.08	0.042
08-Dec-17		3.07	0.018		3.07	0.029

The tracer tests were conducted with the cyclones running at an average pressure of 130 kPa.

Plant Operation
The pressure and density remained stable over the operation period. Refer to Appendices A and B for data as provided by the client.

Thickness Measurements
A thickness gauge was used to measure wear on the individual cyclone components. Tables II and III list the results per cyclone.

Table II.Cyclone 1 wear - between inspections.

Item	Description	Percentage wear (2 months)
1	Cone frustum	4%
2	Inlet section	7%
3	Spigot	9%
4	Overflow bend	16%

Table III. Cyclone 2 - wear between inspections.

Item	Description	Percentage wear (2 months)
1	Cone frustum	9.5%
2	Inlet section	No measured wear
3	Spigot	No measured wear
4	Overflow Bend	24%

The plant was advised to replace the cyclones as the wear rate wear observed on the overflow bend had accelerated between the two inspections, indicating the likelihood of similar wear on the vortex finder. The measurements indicated an average 16% and 24% wear on each of the cyclones between the two inspection dates. The cyclones have treated approximately 40% more tons than the standard set by the mine.

Weir had requested for the cyclones to be made available for further investigation on the actual wear per component at the Weir premises. This will provide a more comprehensive result on wear on the individual cyclone components during operation. This inspection will be particularly important for determining the actual wear on the vortex finder, which was not measured during operation. The cyclones are currently being scanned to determine the degree of wear on each component. Results will be shared once available.

Table IV. Comparison of unit cost between Cavex and conventional cyclone.

Indicative unit cost per module	
400CVXA20	R10 000 per month
Equivalent conventional cyclone	R17 200 per month

Table IV above shows a comparison of the indicative unit cost per module between the Cavex 400CVXA20 cyclone and an equivalent conventional cyclone

CONCLUSION

The two Cavex cyclones installed were able to meet the client requirements. The cyclones were able to achieve an EP well below the set maximum of 0.08 and achieved a cut-point of 3.08 t/m^3 for both the 4 mm and 8 mm tracers. The cyclones also treated 40% more tons than the standard set by the mine. Results are within the client-specified key performance indicators.

The measurements indicated an average 16% and 24% wear on each of the cyclones between the two inspection dates. The recommendation to remove the cyclones was subject to the measurements done on the overflow bends. Further inspections are due to be done to determine possible prolonged use of the cyclones without compromising the efficiencies required by the client.

Future work will include the investigation of various alloys to combat high wear rates on some of the cyclone components, in particular the vortex finder and cone sections of the Cavex HM cyclone. The aim of this exercise is to allow for longer periods of operation, which will further ensure plant stability and will ultimately result in various benefits for the end user.

APPENDIX A: PRESSURE READING – October to December 2017

Time	Cyclone 1	Cyclone 2
2-Oct-17	129.281619	127.305352
43012,4386342	126.954024	123.635824
43013,9113888	104.905126	104.695816
43015,3841435	144.134929	138.741771
43016,8568981	137.574939	129.668817
43018,3296527	131.875116	131.763386
43019,8024074	130.353997	130.352115
43021,2751620	137.341377	137.320878
43022,7479166	140.08699	140.06804
43024,2206712	132.148772	131.909517
43025,6934259	139.775268	134.935064
43027,1661805	120.222884	117.043543
43028,6389351	132.059959	132.126415
43030,1116898	131.230841	131.351422
43031,5844444	130.551368	131.339879
43033,0571990	133.285737	132.098707
43034,5299537	125.335852	126.582095
43036,0027083	129.349156	129.368979
43037,4754629	117.825323	118.302235
43038,9482175	136.706264	137.094997
43040,4209722	118.155671	118.181412
43041,8937268	100.263342	100.498391
43043,3664814	132.350877	132.28157
43044,8392361	132.684687	132.646617
43046,3119907	138.669921	138.925639
43047,7847453	139.750871	139.525263
43049,2575	129.655958	129.768259
43050,7302546	142.507801	129.013745
43052,2030092	141.570517	132.825603
43053,6757638	126.294004	126.329046
43055,1485185	130.354376	132.268918
43056,6212731	90.128388	90.012289
43058,0940277	80.22808	80.153597
43059,5667824	86.250662	84.796734
43061,0395370	116.690652	116.867408
43062,5122916	135.397127	133.757556
43063,9850347	143.109389	131.467487
43065,4577893	139.870781	127.760443
43066,9305439	138.118915	133.514508
43068,4032986	132.76838	133.044729
43069,8760532	139.823144	140.420906
43071,3488078	139.301667	137.632052
43072,8215625	138.067349	138.290262
43074,2943171	135.830695	132.417447
43075,7670717	131.585411	122.178205
43077,2398263	114.74859	114.726889
43078,7125810	129.166108	129.168155
43080,1853356	129.960176	129.937178
43081,6580902	127.997973	128.011833
43083,1308449	114.060074	114.294937
43084,6035995	137.685315	139.550327
17-Dec-17	130.695041	124.31565
AVERAGE	**128**	**127**

APPENDIX B: DENSITY READING – December 2016 to December 2017

Time	Density Reading		Time	Density Reading		Time	Density Reading
27-Dec-16	2.59		42848,962881944448	2.63		42968,255995370368	2.64
42732,615266203706	2.65		42850,435636574075	2.62		42969,728750000002	2.61
42734,088020833333	2.64		42851,908391203702	2.24		42971,201504629629	2.63
42735,56077546296	2.52		42853,381145833337	2.00		42972,674259259256	2.63
42737,033530092594	2.59		42854,853888888887	2.01		42974,147013888891	2.64
42738,506284722222	2.63		42856,326643518521	2.20		42975,619768518518	2.62
42739,979039351849	2.65		42857,799398148149	2.60		42977,092523148145	2.63
42741,451793981483	2.65		42859,272152777776	2.63		42978,56527777778	2.44
42742,92454861111	2.65		42860,74490740741	2.65		42980,038032407407	2.65
42744,397303240738	2.60		42862,217662037037	2.63		42981,510787037034	2.64
42745,870057870372	2.57		42863,690416666665	2.63		42982,983541666668	2.64
42747,342812499999	2.56		42865,163171296299	2.63		42984,456296296295	2.51
42748,815567129626	2.47		42866,635925925926	2.63		42985,929050925923	2.60
42750,288321759261	2.59		42868,108680555553	2.64		42987,401805555557	2.65
42751,761076388888	2.63		42869,581435185188	2.65		42988,874560185184	2.64
42753,233831018515	2.60		42871,054189814815	2.63		42990,347314814811	2.61
42754,706585648149	2.38		42872,526944444442	2.63		42991,820069444446	2.51
42756,179340277777	2.64		42873,999699074076	2.42		42993,292824074073	2.46
42757,652094907404	2.64		42875,472453703704	2.51		42994,7655787037	2.65
42759,124849537038	2.50		42876,945208333331	2.61		42996,238333333335	2.63
42760,597604166665	2.60		42878,417962962965	2.52		42997,711087962962	2.61
42762,0703587963	2.64		42879,890717592592	2.65		42999,183842592596	2.16
42763,543113425927	2.64		42881,36347222222	2.63		43000,656597222223	2.55
42765,015868055554	2.53		42882,836226851854	2.64		43002,129351851851	2.64
42766,488622685189	2.61		42884,308981481481	2.65		43003,602106481485	2.65
42767,961377314816	2.42		42885,781736111108	2.55		43005,074861111112	2.61
42769,434131944443	2.64		42887,254490740743	2.38		43006,547615740739	2.27
42770,906886574077	2.56		42888,72724537037	2.65		43008,020370370374	2.64
42772,379641203705	2.58		42890,199999999997	2.65		43009,493125000001	2.63
42773,852395833332	2.61		42891,672754629632	2.64		2-Oct-17	2.62
42775,325150462966	2.61		42893,145509259259	2.64		43012,438634259262	2.54
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42785,634432870371	2.65		42903,454791666663	2.65		43022,747916666667	2.65
42787,107187499998	2.60		42904,927546296298	2.65		43024,220671296294	2.60
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42794,470960648148	2.58		42912,291319444441	2.64		43031,584444444445	2.62
42795,943715277775	2.34		42913,764074074075	2.60		43033,057199074072	2.63
42797,41646990741	2.64		42915,236828703702	2.61		43034,529953703706	2.55
42798,889224537037	2.63		42916,709583333337	2.65		43036,002708333333	2.63
42800,361979166664	2.55		42918,182337962964	2.63		43037,475462962961	2.48
42801,834733796299	2.46		42919,655092592591	2.61		43038,948217592595	2.63
42803,307488425926	2.49		42921,127847222226	2.60		43040,420972222222	2.43
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42806,252997685187	2.56		42924,07335648148	2.64		43043,366481481484	2.65
42807,725752314815	2.47		42925,546111111114	2.59		43044,839236111111	2.65
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42828,344317129631	2.64		42946,164675925924	2.61		43065,457789351851	2.65
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42831,289826388886	2.43		42949,110185185185	2.48		43068,403298611112	2.59
42832,76258101852	2.57		42950,582939814813	2.51		43069,87605324074	2.65
42834,235335648147	2.64		42952,055694444447	2.62		43071,348807870374	2.64
42835,708090277774	2.64		42953,528449074074	2.62		43072,821562500001	2.64
42837,180844907409	2.60		42955,001203703701	2.65		43074,294317129628	2.64
42838,653599537036	2.62		42956,473958333336	2.65		43075,767071759263	2.53
42840,126354166663	2.64		42957,946712962963	2.64		43077,23982638889	2.48
42841,599108796298	2.64		42959,41946759259	2.65		43078,712581018517	2.65
42843,071863425925	2.64		42960,892222222225	2.64		43080,185335648152	2.65
42844,544618055559	2.59		42962,364976851852	2.63		43081,658090277779	2.64
42846,017372685186	2.38		42963,837731481479	2.51		43083,130844907406	2.47
42847,490127314813	2.57		42965,310486111113	2.57		43084,60359953704	2.63
			42966,78324074074	2.64		17-Dec-17	2.64
						AVERAGE	**2.59**

REFERENCES

Bosman, J. (2008). Dense medium cyclone selection – A size based approach. *Proceedings of the Coal Preparation Conference*, Secunda, South Africa, 10-14 September 2009.

Legault-Seguin, E. Mohns, C. ,and Rylatt, M 2016. Dense medium separation – An effective and robust pre-concentration technology. SGS Canada Inc.

Ndlovu, S. (Not dated). DMS cyclone efficiency factors: the De Beers perspective**.** De Beers Group.

Rodel, A and Roode, L. (Not dated). DMS efficiency monitoring.

Singleton, J.D. (2013). Development and evaluation of a dense media cyclone for the Southern African mineral and coal industries. Faculty of Engineering and the Built Environment, University of the Witwatersrand. http://hdl.handle.net10539/13941

Weir Minerals Africa. (2014). Cavex® CVX dense medium cyclones. (Brochure). Weir Minerals Africa, Johannesburg

Wills, B.A. (2006). *Mineral Processing Technology: An Introduction to the practical aspects of Ore Treatment and Mineral Recovery***.** 7th edn. Butterworth Heinemann, Oxford. pp. 220, 246-266.