NEAR-GRAVITY MATERIAL EXPERIENCE AT LEEUWPAN COAL MINE

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ABSTRACT

Near-gravity material (NGM) is traditionally defined as coal and discard particles that are within ±0.1RD of the separation density attained in the dense medium cyclone. The amount of NGM in the Leeuwpan coal has been quantified to be as high as 80%. The treatment of this material resulted in lowered organic efficiencies and increased misplacement which was through loss of product in the discard stream, and contamination of product stream with discard particles. The latter effect made it extremely difficult to achieve the desired product qualities when processing coal with excessive NGM. This effect was most severe in the 710mm cyclones that beneficiate the -6+0.6mm fraction. In order to alleviate this problem the plant tempos had to be reduced to about 50-70% of normal operation.

Two initiatives were implemented to address the difficulties associated with excessive NGM, namely: larger diameter cyclone and blending of high-NGM coal with low-NGM coal from other reserves. Through these two initiatives problems associated with excessive NGM were alleviated, and the plant could be operated closer to its design capacities.

1. INTRODUCTION

1.1. Leeuwpan Coal Mine

The DMS plant at Leeuwpan coal mine has two identical modules and a Wemco drum. Each module has two dense medium cyclones (710mm and 800mm in diameter), and a further two small cyclones (420mm and 360mm in diameter) that replaced the spiral circuit. Coal particles are beneficiated in the different equipments on the basis of size; namely:

- Wemco drum : +25mm
- 800mm Cyclone : -25+6mm
- 710mm Cyclone : -6+0.6mm
- 420mm and 360mm Cyclones : -0.6+0.2mm

A flow-diagram showing the DMS plant at Leeuwpan is given in Fig. 1.

1.2. Near-Gravity Material

Near-gravity material (or near density material), abbreviated NGM, is traditionally defined as referring to coal and discard particles that are within ±0.1RD of the separation density attained in the separation device, namely the dense medium cyclone. NGM has also been defined in terms of ±0.05RD within separation density and ±Epm (*Escart Probable Moyen*) value within separation density (de Korte, 2008).

The amount of NGM in the Leeuwpan coal has been quantified to be as high as 80% (within ±0.1RD of the separation density); alternatively this can be expressed as maximum of 60% (within ±0.05RD). An example of a washability typically encountered at Leeuwpan is illustrated in Fig. 2; the maximum possible amount of NGM in this particular case was 54% (within ±0.05RD) at cut-density of 1.5RD.

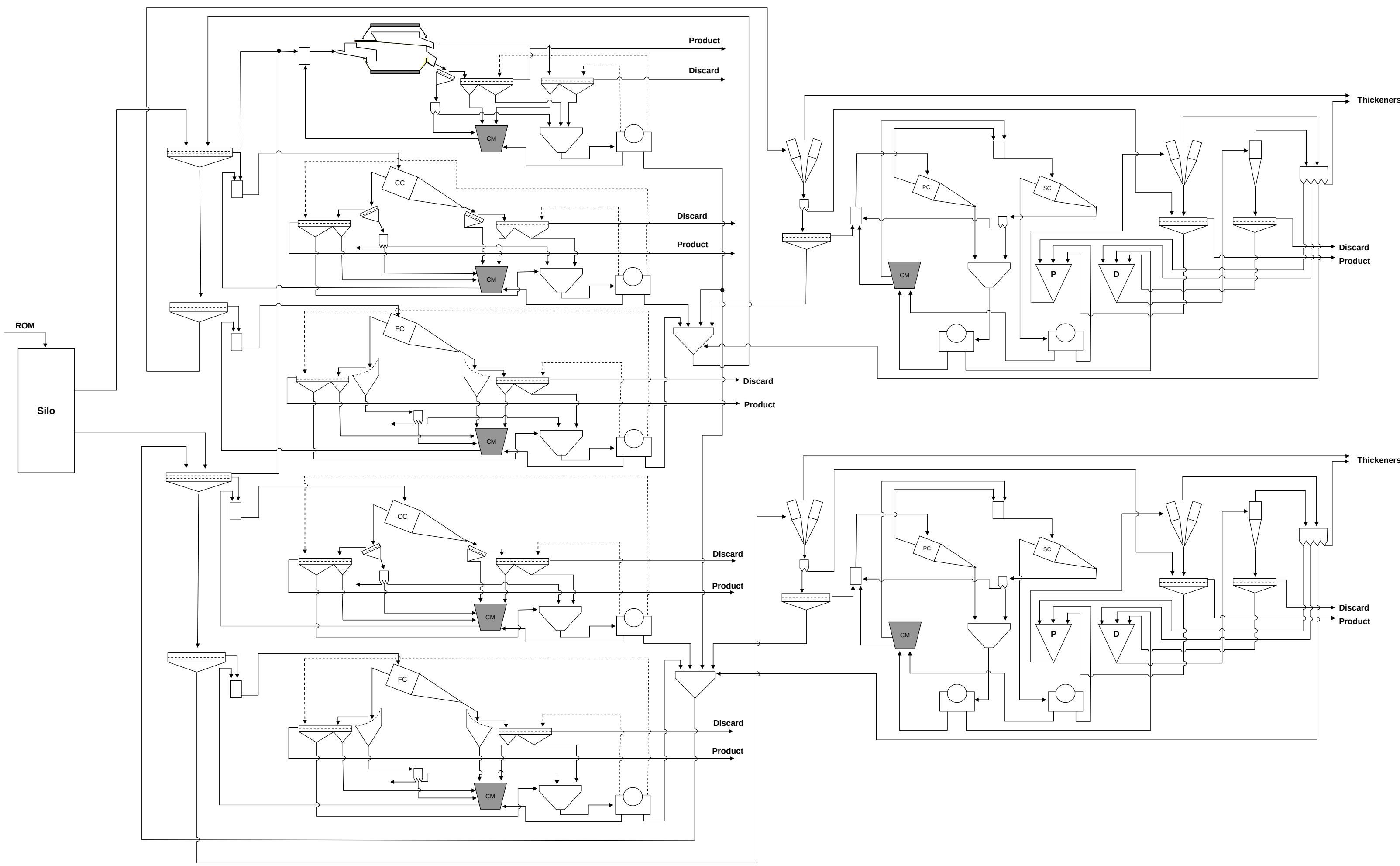

Figure 1. Flow-diagram of the DMS plant at Leeuwpan Coal Mine.

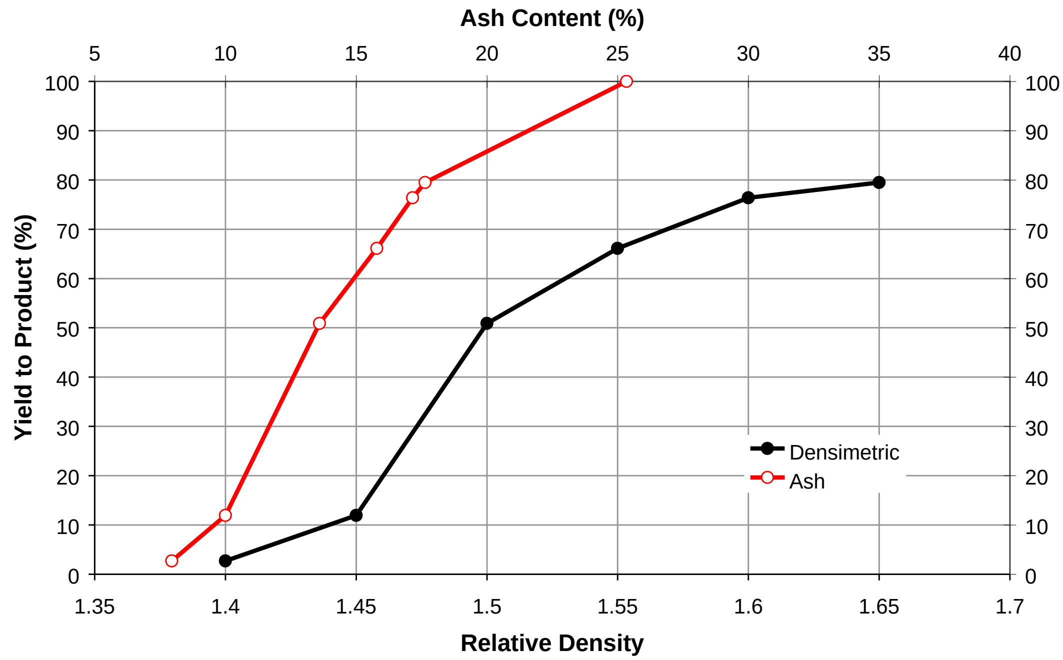

Figure 2. Typical washability of coal with excessive near-gravity material.

1.2.1 Why Does Excessive NGM Make Separation Difficult?

A study by Napier-Munn (1985) on the residence time of particles within a dense medium cyclone revealed that "the distribution of mean residence time with particle density is normal in nature; the longest residence times are exhibited by particles that have densities close to the prevailing separating density". Particles with very low or very high densities were observed to exhibit the shortest residence times. This behaviour is illustrated in Fig. 3 for two hypothetical coal types: one with high NGM and another with low NGM. The residence time of a particle with a density equal to the separation density is expected to decrease when there is lower NGM within the coal type; this is because there would be reduced interaction between near-dense particles as a result of reduction in the proportion of these particles in the feed. Furthermore, the residence times of particles with very low or very high densities are expected to increase due to increased interaction of these fractions when NGM is lower.

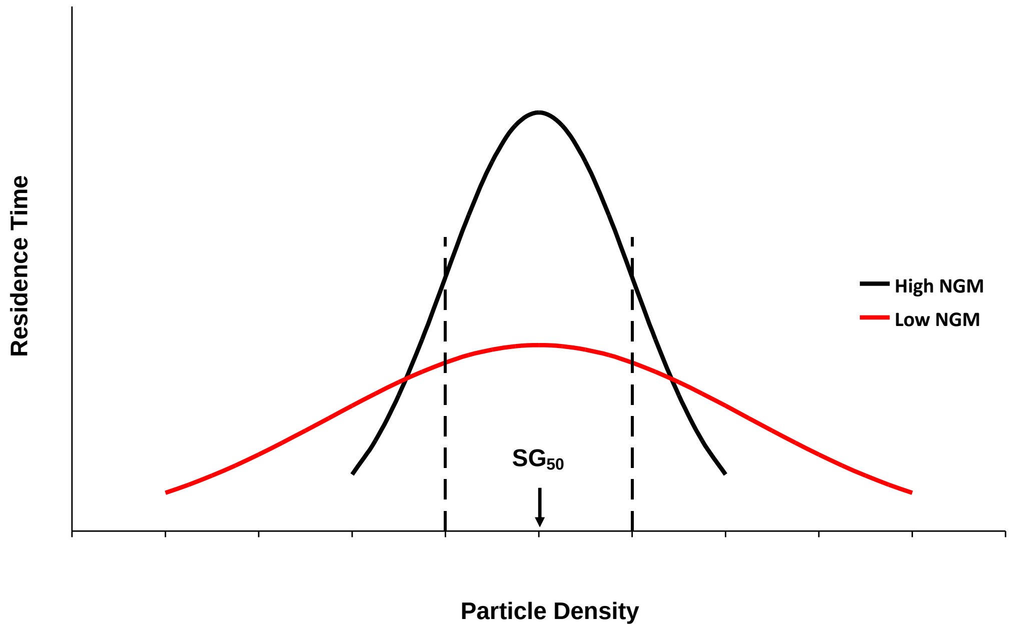

Figure 3. Conceptual illustration of residence time behavior for particles of different densities within a dense medium cyclone.

Particles with densities close to the separation density have a higher probability of being misplaced due to the long residence times associated with these particles. It is expected that the probability of particle misplacement is increased further if the proportion of near-dense particles in the feed is higher. It is this behaviour of particles with densities close to the separating density that makes it difficult to beneficiate coals with excessive NGM.

1.2.2 The Effect of NGM on Separation Process

Excessive amount of NGM in the feed of a dense medium cyclone is detrimental to the effectiveness of the cyclone in beneficiating the coal. The impact of NGM on the dense medium processes has previously been reported to be mainly through a lowered organic efficiency and increased misplacement of particles to the incorrect streams. (Horsfall, 1987; de Korte, 2008)

The effect of NGM typically encountered at Leeuwpan is shown in Fig. 4 and Table 1, which illustrate the cyclone performance when beneficiating coal with excessive NGM. Although the EPM of 0.02 is reasonable, the amount of misplacement encountered was extremely high at around 14%. Typically, misplacement observed in these cyclones is around 1-3%. The organic efficiency observed was 78% as opposed to typical values within the range 95-100%.

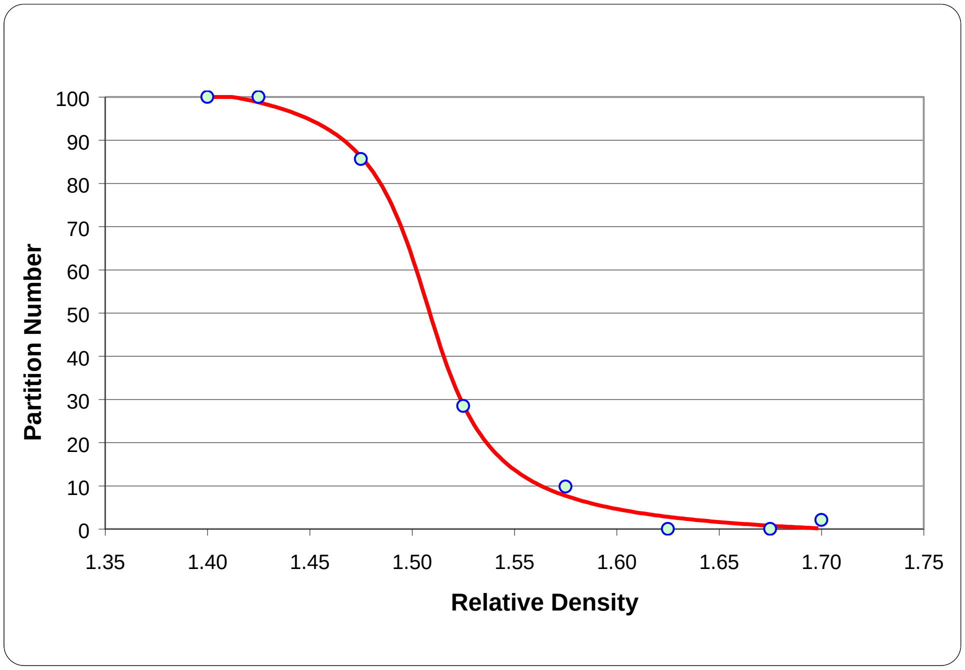

Figure 4. Partition curve of a cyclone beneficiating coal with excessive near-gravity material.

Table 1. Cyclone performance when beneficiating coal with excessive near-gravity material (For partition curve in Fig. 4).

SG_{50} (t/m^3)	EPM (t/m^3)	Misplacement (%)	Organic Efficiency (%)
1.51	0.02	14	78

A consequence of the lowered organic efficiency and increased misplacement is obviously loss of product in the discard stream, and contamination of product stream with discard particles. The latter effect made it extremely difficult to achieve the desired product qualities when processing coal with excessive NGM. This effect was more severe in the 710mm dense medium cyclones that beneficiate the -6+0.6mm fraction than in the 800mm cyclones. In order to deal with this problem the plant tempos had to be reduced to about 50-70% of normal operation. Reducing the coal feed rate into the plant had the effect of increasing the medium-to-coal ratio in the cyclone feed, which is why this assisted to an extent in alleviating the impact of excessive NGM. This, however, was not an attractive solution due to the consequent reduction in the plant throughput.

2. ALTERNATIVE MEASURES TO DEAL WITH EXCESSIVE NGM

2.1. Changes around the Dense Medium Cyclone

There are four main cyclone parameters that can be manipulated to deal with excessive near-gravity material; namely: *barrel length*, feed *medium-to-coal ratio, spigot diameter*, and *cyclone diameter*. The impact of these variables is discussed in more detail in the ensuing paragraphs.

2.1.1. Barrel Length

A barrel is normally inserted into a cyclone that is used to beneficiate coal with excessive near gravity material. A longer cylindrical section is thought to increase the separation efficiency of the cyclone through increased residence time within the equipment. The standard barrel length is about 0.6 x cyclone diameter. The two 710mm dense medium cyclones at Leeuwpan each already had a barrel length of approximately 0.6x cyclone diameter.

2.1.2. Feed Medium-to-Coal Ratio

The recommended medium-to-coal ratio in the cyclone feed when treating South African coals with excessive near-gravity material is 3.5:1 (Peatfield, 2003). Dense medium cyclones that operate at medium-to-coal ratios below 3.5:1, when treating coal with high amounts of near-gravity material, tend to be inefficient and excessive misplacement takes place. Generally, the higher the feed medium-to-coal ratio the easier it is for the cyclone to beneficiate coals with excessive near-gravity material. There is an upper limit beyond which further increase in the medium-to-coal ratio no longer makes a difference. At Leeuwpan this effect was encountered when plant throughput was less than 50% of normal operation.

2.1.3. Spigot Diameter

According to Sripriya *et al*. (2001), high feed rates in the presence of a large proportion of NGM causes the build up of near-dense particles inside the cyclone. This becomes a problem when the spigots are not large enough to discharge the whole quantity of the discards resulting in some of these particles, which cannot discharge through the spigot, moving to the vortex finder. This build-up of near-dense particles is also said to result in congestion around the spigot, which can eventually result in (temporary) breakdown of the medium flow pattern.

Thus, the ability of a dense medium cyclone to handle excessive near-gravity material can be improved by increasing the spigot diameter. A larger spigot diameter alleviates overloading of the spigot, and thus reduces the risk of misplacing the discard to the clean coal product. This option is, however, not applicable for Leeuwpan’s cyclones (all four: 2x710mm and 2x800mm) because these cyclones are already operating with the maximum spigot diameters that are allowable for these cyclones.

An alternative view has previously been presented by He and Laskowski (1995) who postulated 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 smaller spigot is said to improve their chance of reporting to the correct product streams.

2.1.4. Cyclone Diameter

Increasing the cyclone diameter is also thought to improve the cyclone's ability to beneficiate coals with excessive near-gravity material. This is so because much higher cyclone throughput can be achieved, whilst operating with relatively high medium-to-coal ratios, when operating with a larger cyclone. Thus, higher cyclone throughput can be achieved and simultaneously obtain the desired coal qualities due to the cyclone being more efficient at relatively high medium-to coal ratios when processing coal with excessive NGM. A possible option is, therefore, to replace the 710mm cyclone with an 800mm one.

Of these four options, only changing of the cyclone diameter from 710mm to 800mm was attractive.

2.2 Blending High-NGM Coal with Low-NGM Coal

An alternative way of dealing with NGM is to blend high-NGM coal with a low-NGM one. The expected effect of blending coals with high-NGM together with a low-NGM is reflected in Table 2 where NGM is defined to be within ±0.1RD of the separation density. It is clear from Table 2 that the negative effect of excessive NGM can be mitigated by producing high-NGM coal in conjunction with a low-NGM one. Figs. 5 and 6 show the washabilities of the low-NGM and high-NGM coals used to produce Table 2. The practicalities of blending coal from two reserves on the Run-Of-Mine circuit before feeding into the plant were, however, found to be too cumbersome.

Table 2. Simulation results illustrating the influence of blending low- and high-NGM coal on the amount of NGM in feed. (Courtesy of G.J de Korte)

%High NGM	%Low NGM	NGM in Feed (%)
100	0	78*
75	25	49.9
50	50	22.5
25	75	3.3

*Percentage of NGM if the separation density had been 1.50RD

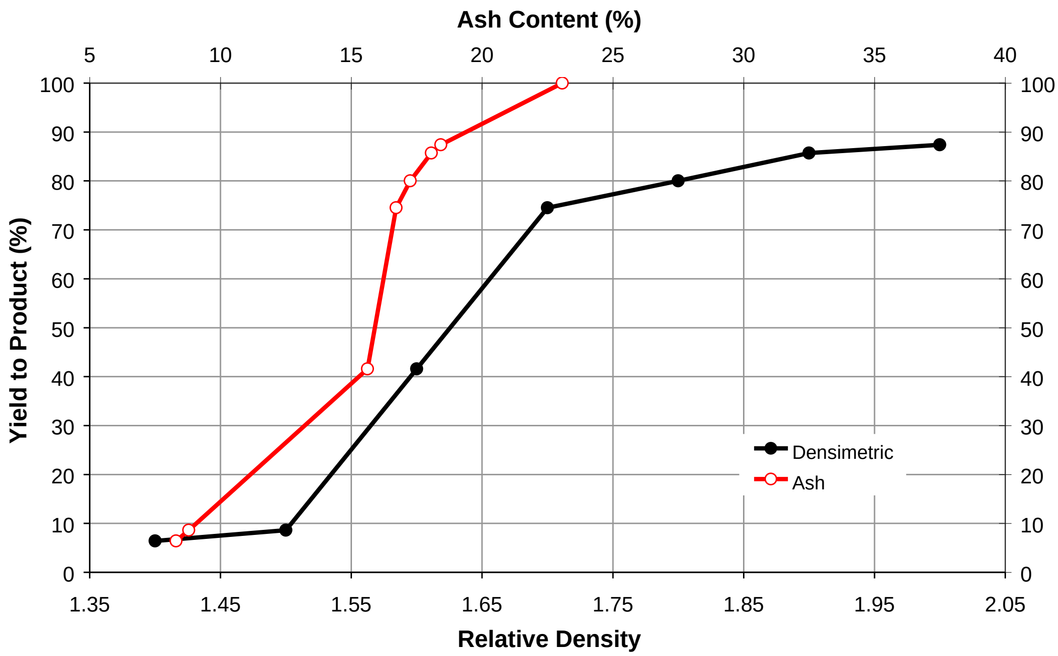

Figure 5. Washability curve for high-NGM coal

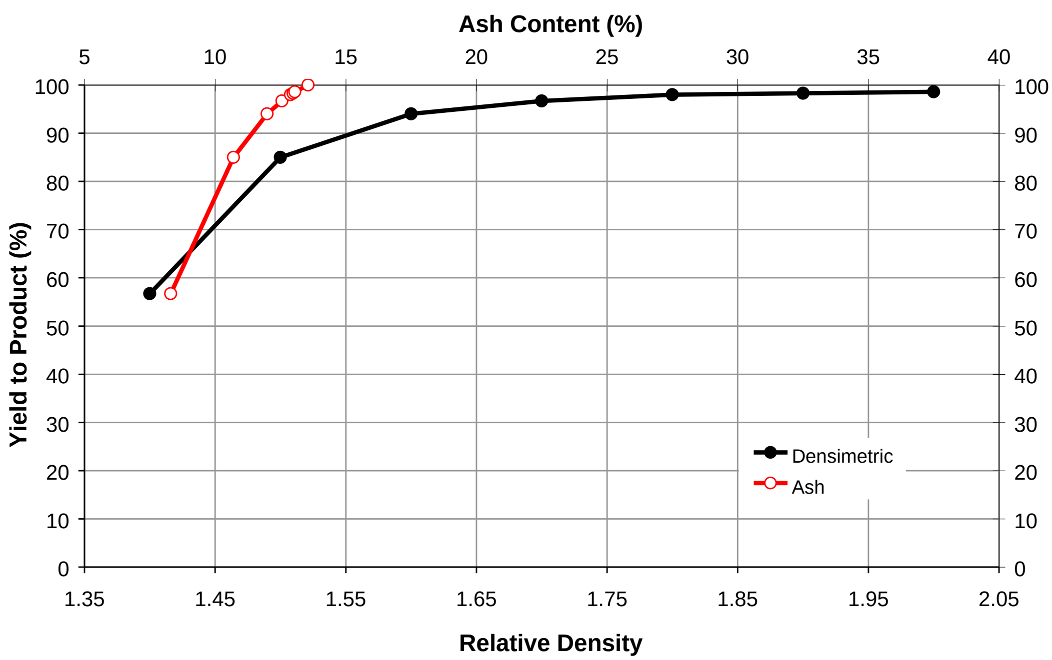

Figure 6. Washability curve for low-NGM coal

It was decided that the blending should instead be performed on the product stockpiles which was found to be more manageable. The logic behind this approach was based on the fact that the high-NGM coal encountered at Leeuwpan consistently exhibited the most near-gravity material within relative densities between 1.45 and 1.55RD (Figs. 2 and 5). As such, the impact of NGM on the beneficiation process could be minimized by operating the cyclones at medium densities outside the 1.45-1.55RD density range. By operating the cyclones outside this range better control over the product ashes could be achieved as a result of the reduction in amount of particle misplacement associated with decreased levels of NGM. This concept is illustrated in Table 3.

Table 3. Effect of increasing the separation density on impact of NGM on separation process (based on washability data presented in Fig. 2).

SG_{50} (t/m^3)	NGM (%)*	Theoretical Yield (%)	Product Ash (%)
1.50	54.2	50.9	13.6
1.55	25.5	66.1	15.8
1.60	13.4	76.4	17.2

*NGM defined as within ±0.05RD of SG_{50}.

As illustrated in Table 3, by operating at higher densities outside the range of maximum NGM the yield benefit is quite significant and misplacement should decrease considerably because of the lowered NGM. A further advantage of this approach is the fact that the plant can be operated closer to its design capacity without worrying too much about excessive misplacement occurring within the cyclone. The one disadvantage of this approach is increased product ashes as shown in Table 3. This could, however, be countered by dove-tailing the production of high-NGM coal with high quality low-NGM from another reserve (such as that presented in Fig. 6).

3. CHANGES THAT WERE IMPLEMENTED

3.1 Larger Diameter Cyclone

An 800mm diameter dense medium cyclone was installed to replace the 710mm diameter cyclone in module 1 of the DMS plant. The 710mm diameter cyclone in module 2 was left unchanged in order to be able to compare it with the larger 800mm cyclone in module 1. The dimensions of the old 710mm and new 800mm cyclones are given in Table 4.

Table 4. Dimensions of the old and new cyclone in module 1.

	Before	After
Cyclone Diameter (mm)	710	800
Inlet (mm x mm)	120x120	135x135
Barrel Length (mm)	426	480
Vortex Finder Diameter (mm)	305	344
Spigot Diameter (mm)	248	276
Cone Angle (deg.)	20	20

3.2 Blending of High-NGM Coal with Low-NGM Coal

Blending of high-NGM together with low-NGM involved scheduling of the high-NGM coal on one shift followed by a shift of low-NGM coal such that on a particular day both coal types were beneficiated. In order for this shift-by-shift dove-tailing of high-NGM and low-NGM coals to function involvement of all parts of the core value chain was essential of which the relevant simplified process flow is illustrated in Fig 7.

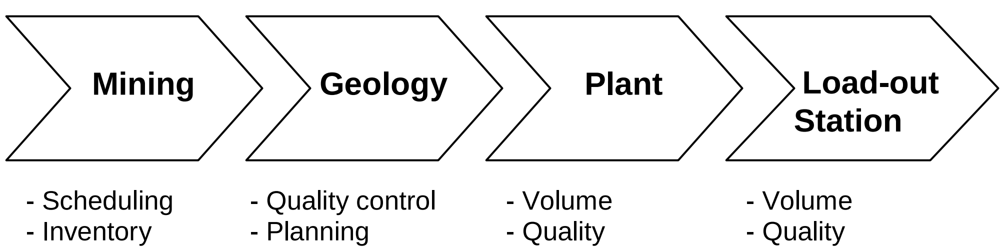

Figure 7. Simplified process flow approach employed to ensure optimum dove-tailing of high-NGM coal with low-NGM coal.

Inventory availability was extremely crucial to this process because it ensured flexibility which enabled this process to accommodate variations in the coal behaviour and other factors such as human resources, equipment availabilities, etc

4. RESULTS AND DISCUSSION

4.1 Effect of Installing a Larger Dense Medium Cyclone

Fig. 8 illustrates the product ashes achieved in the 710mm cyclone on module 2 (before and after changing the cyclone diameter in module 1). The product ashes given in Fig. 8 reflect data from a period of about five months before the implementation of the solution and about three months after the implementation.

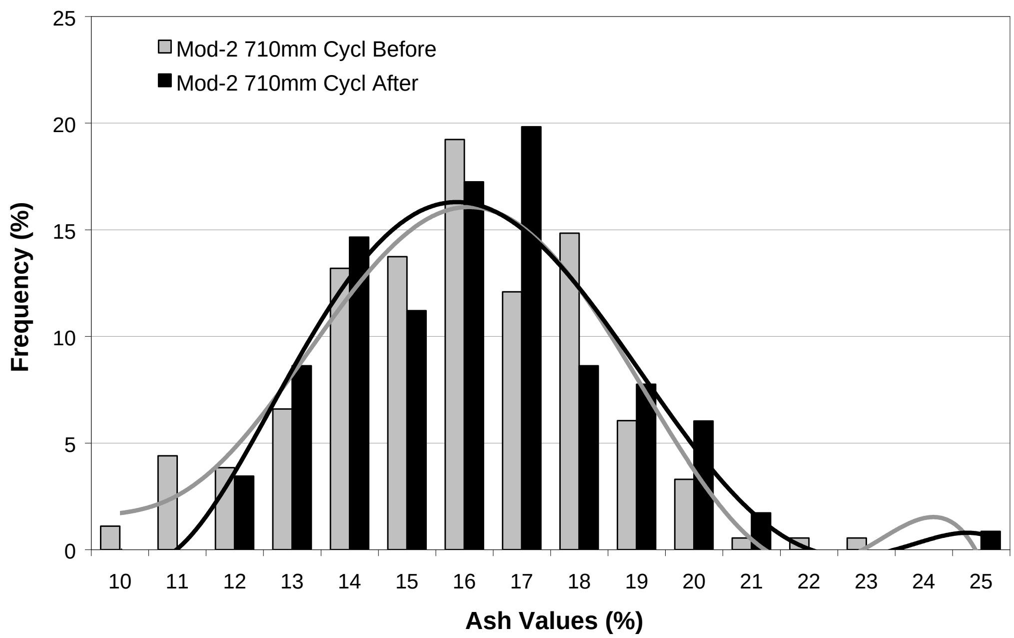

Figure 8. Product ashes achieved in the 710mm cyclone in module 2 before and after the cyclone size was changed in module 1.

There is no discernable difference between the product ashes achieved in the cyclone in module 2 before and after the change to cyclone diameter in module 1 was made. This is further confirmed by the t-test results given in Table 5.

Table 5. t-Test (Two-sample assuming equal variances) results for the 710mm cyclone in module 2.

	Ash (Before)	*Ash (After)*
Mean	15.8	16.2
Variance	5.5	5.4
Observations	182	116
Pooled Variance	5.5	
Hypothesized Mean Difference	0	
df	296	
t Stat	-1.54	
P(T<=t) one-tail	0.06	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.13	
t Critical two-tail	1.97	

Comparison of the product ashes achieved with the new 800mm cyclone in module 1 before and after the cyclone diameter in module 1 was changed is illustrated in Fig. 9. The data in Fig. 9 was over the same time period as that presented in Fig. 8 for the 710mm cyclone in module 2. Thus, at any point in time the cyclones in module 1 and 2 generally processed the same coal.

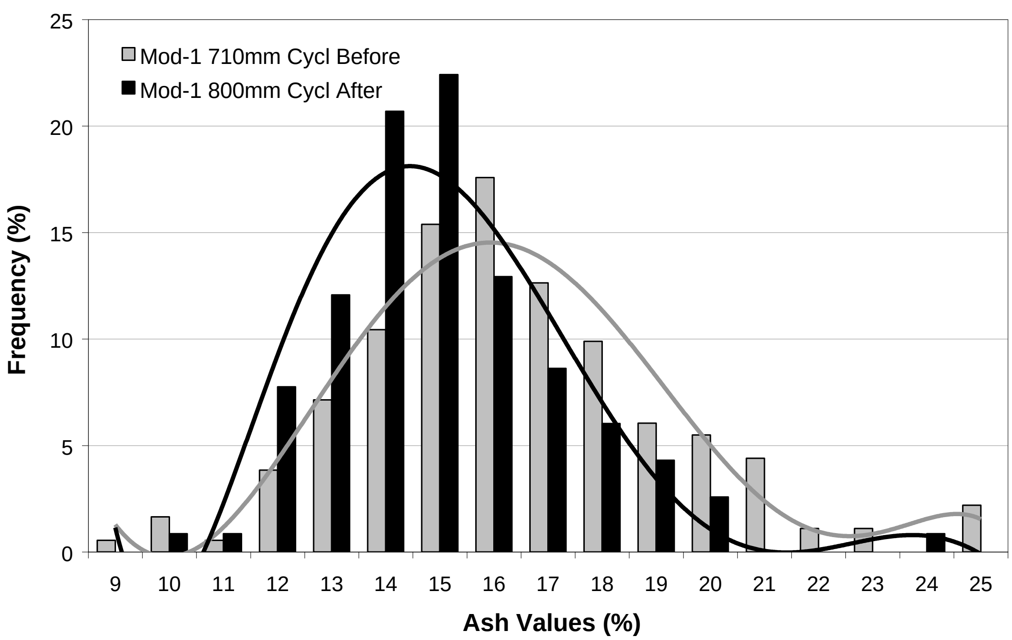

Figure 9. Product ashes achieved in the new 800mm cyclone in module 1 before and after the cyclone size was changed.

There is a clear shift in the product ashes achieved in the new 800mm cyclone from an average of 16.3% to 15.1%. A t-test comparison of the two data sets (before and after the cyclone diameter in module 1 was changed) confirms that the change in the product ashes is statistically significant (Table 6).The change in the product ashes was not just the general decrease in the values, the product ashes were produced in a narrower range than before. It can, therefore, be concluded that increasing the cyclone diameter had a positive impact on the equipment's effectiveness in beneficiating coal with excessive NGM.

Table 6. t-Test (Two-sample assuming unequal variances) results for the 800mm cyclone in module 1.

	Ash (Before)	***Ash (After)***
Mean	16.3	15.1
Variance	8.3	5.0
Observations	182	116
Hypothesized Mean Difference	0	
df	285	
t Stat	4.30	
P(T<=t) one-tail	1.19×10^{-5}	
t Critical one-tail	1.65	
P(T<=t) two-tail	2.40×10^{-5}	
t Critical two-tail	1.97	

There exists a minimum particle size below which the separation efficiency of a particular dense medium cyclone begins to deteriorate. This particle size is referred to as the *breakaway size* (Bosman and de Korte, 2006). The breakaway size increases exponentially with increasing cyclone diameter according to Bosman and de Korte. The breakaway size for a 710mm cyclone has been estimated to be around 2.7mm whilst that for an 800mm cyclone is around 3.5mm. The proportion of the cyclone feed for the new 800mm cyclone that is less than 3.35mm is roughly about 35–60% of the feed; this size fraction constitute a significant amount of the cyclone feed.

It would, therefore, be expected that there could be a potential deterioration in the separation efficiency in the new larger 800mm cyclone. The cyclone performance of the new 800mm cyclone is reflected in Fig. 10 and Table 7. The coal beneficiated in this case did not have excessive NGM. The separation efficiency achieved with the new 800mm cyclone is quite reasonable. The amount of misplacement (about 2%) that occurred is acceptable, and is within typical values encountered when processing low-NGM coal before the cyclone diameter was changed.

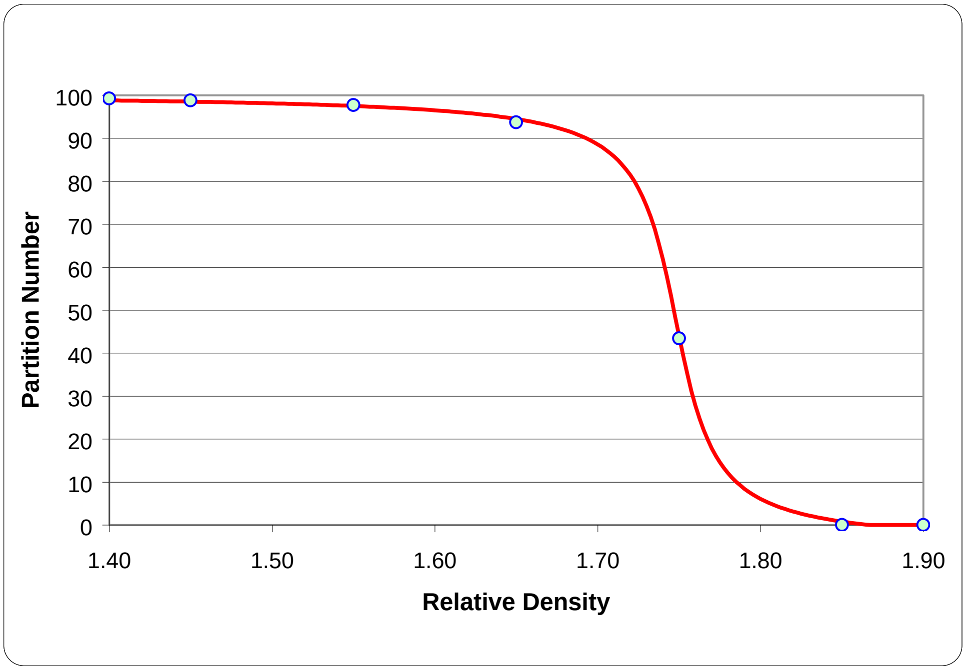

Figure 10. Cyclone performance after increasing the cyclone diameter from 710mm to 800mm.

Table 7. Performance of the new 800mm cyclone.

SG_{50} (t/m^3)	EPM (t/m^3)	Misplacement (%)	Organic Efficiency (%)
1.75	0.0166	1.9	98.6

4.2 Effect of Dove-tailing High-NGM with Low-NGM

Blending of the low-NGM coal with high-NGM coal on the product stockpiles enabled the supply of a product that was constantly within specification to the relevant customers. With this process the yields of the two coal types could be maximized and when high product ashes were attained from the high-NGM this could easily be blended with the lower ashes produced from the low-NGM coal. Due to the very low ashes (still at high yields) that could be achieved with the low-NGM coals, there was no loss in yield as a consequence of the blending of the two coal types.

The effect of these two initiatives (blending and larger cyclone diameter) is illustrated in Fig. 11. Before these two initiatives were implemented in June the capacity utilization in the DMS plant was low because the plant was operated at roughly 50-70% of normal plant throughput in order to accommodate coal with excessive NGM. Since then the improvement in the plant throughput has been significant.

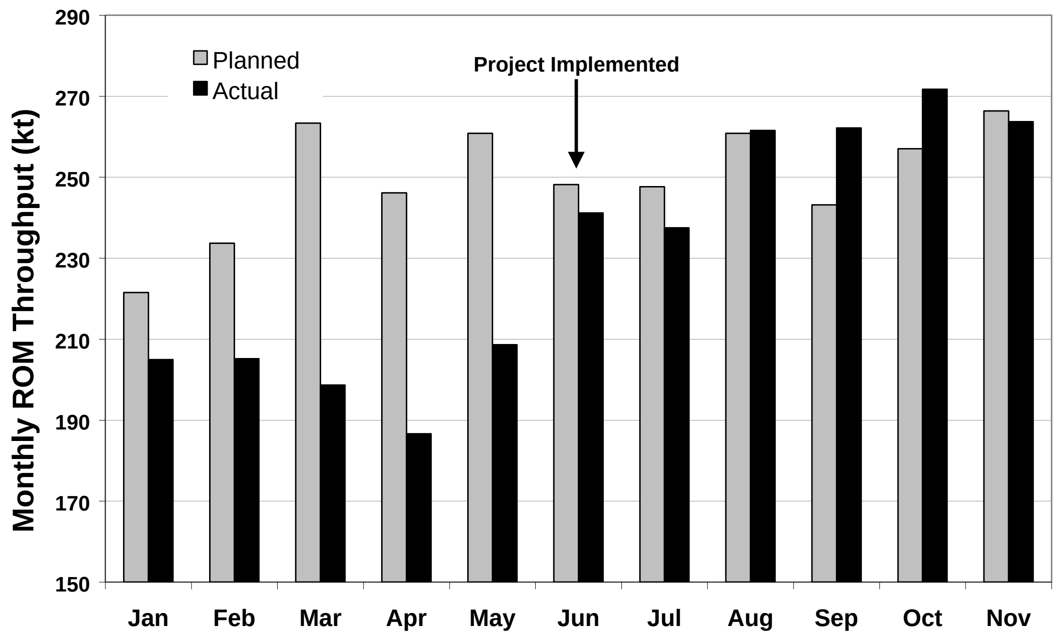

Figure 11. The change in capacity utilization of the DMS plant.

5. CONCLUSIONS

Increasing the diameter of the 710mm dense medium cyclone, which beneficiates the -6+0.6mm fraction, to 800mm had a beneficial effect on the equipment's ability to beneficiate coal with excessive near-gravity material. Furthermore, by producing the high-NGM coal with low-NGM coal from other reserves in a batching mode the occasional high product ashes from the high-NGM coal could easily be blended with the product derived from low-NGM coals.

6. ACKNOWLEDGEMENTS

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