Dry processing for coal preparation: a review

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Utilizing dry coal beneficiation as opposed to the conventional wet methods arises for numerous reasons including the scarcity of water in some regions such as South Africa, the associated costs of product and fine material de-watering and handling and also erecting plants that are economically feasible for small or remote reserves. Dry coal processing benefits downstream utilizations through possible cost and energy savings along with a reduction in water pollution. As a result, dry beneficiation has inspired interest in the South African coal preparation industry and research into many methods has commenced with respect to the local coals.

Addendum B:

Applicability of dry coal processing to the South African coal market

Herein, the applicability of dry coal processing techniques to the South African coal market is addressed. A discussion regarding the current market in South Africa and the potential benefits that dry coal processing may have is provided. The most suitable processing methods for the current and future demands are listed along with the reasons they are preferred. The addendum is concluded with a note on the future of dry coal beneficiation in South Africa.

The global coal market

On a global scale, coal forms an important source of energy and fuels approximately 29% of the planet's energy requirements (WEC, 2017). With 892 billion tons of recoverable coal reserves worldwide, it is in no doubt that this affordable, abundant and widespread resource is responsible for meeting a great deal of the international energy demand and will continue to do so for roughly 114 years to come (WCA, 2009; IEA, 2018). Coal originates in 70 countries across the globe with the main reserves located in the

Americas, Europe, Africa, the Middle East, China and the Asia Pacific (WCA, 2009; Prevost, 2018). More or less 50 of these countries actively mine coal with the key contributors being as listed in Table 1.

Table 1: Top 10 major global coal producers (IEA, 2018; Prevost, 2018)

Country	Estimated Mt produced (2017)
China	3376.1
India	729.8
United States	702.3
Australia	501.1
Indonesia	487.6
Russian Federation	387.2
South Africa	252.3
Germany	175.1
Poland	127.0
Kazakhstan	106.0
Other	699.5
Total world production	**7544.0**

From Table 1, a steep incline in global coal production is observed since 2003 where the total world coal production ranged in 5000 Mt (Prevost, 2018). The world consumes well over 4050 Mt of coal annually in a number of sectors - including power generation, iron and steel production, cement manufacture and as a liquid fuel (WCA, 2009). Much of the coal produced globally is utilized in the country of production with approximately 18% destined for the international coal market (WCA, 2009). The key world coal exporters in decreasing order of contribution are Indonesia, Australia, the Russian Federation, USA, Colombia, South Africa, Mongolia, Canada, Kazakhstan and the Netherlands (IEA, 2018). The International Energy Agency reports a 3.3% increase in all coal exports for 2017 with a 26.2 and 13.9 million ton increase, respectively, for steam and coking coal exports. Indonesia and Australia remain the largest global exporters of coal with respectively, 28.5% and 27.6% of exports (IEA, 2018; Prevost, 2018). Some of the major coal importers include Japan, Korea, China, Germany, UK, Russia, India, USA, Netherlands and Spain (WCA, 2009). In 2017 Indonesia's main coal customers were China, India, Korea and Japan with a total export of 390.6 Mt (IEA, 2017; Prevost, 2018). A significant increase in US exports was observed in 2017 with India, Korea and Japan as the three main destinations - India purchasing nearly three times as much coal as in 2016 (IEA, 2017; Prevost, 2018).

It is essential to understand some recent market-related trends in global coal production and consumption. A report by McCloskey 2018 IHS Markit states that US coal shipments to Asian destinations surpassed those to Europe by 1.2 Mt implying a shift of the tides from a market dominated by Europe and South American trade to include much more of the locales being India, Japan, China and South Korea (IHS Markit (2018) in Prevost, 2018). India proving eager to garner US coals with exports of thermal coal increasing by 63% from 2017 to 2018 (IHS Markit (2018) in Prevost, 2018). Moreover, the increasing efforts to revive the coal industry in the USA with the implementation of new policies designed to support coal-burning plants established the USA once again as a major global export competitor (Puko, 2018). Coal is envisaged to drive the electricity generation in South East Asia by contributing an estimated 800 TWh by 2040 compared to the 300 TWh in 2015 (Energy Outlook, 2017).

Australia has called for more coal-fired plants with the intent of utilizing coal for energy in-house and not to rely merely on export (Australian Associated Press (2018) in Prevost, 2018). On the other hand, many of the European consumers intend to phase coal energy out by 2030 (Prevost 2018). This may, however, prove difficult as some shortfalls in the planning thereto have emerged in especially Germany (Bloomberg (2018) in Prevost, 2018). China has restarted coal plant building due to rebounding power demands. Many of these power plants are however running at a loss due to the substantial overcapacity (Energy post weekly (2018) in Prevost, 2018). The transition towards the lower carbon fuel mix is continuing with renewables fast growing and accounting for 40% of the increase in energy. This provides for a more diversified energy mix and by 2040 oil, gas, coal and non-fossil fuels are predicted to sustain roughly a quarter of the global energy requirements each (BP Energy Outlook, 2018). Significant growth is observed in the natural gas and oil resources until 2040 where coal's predicted contribution remains relatively constant (BP Energy Outlook, 2018).

Coal still plays a major role in the global economy and many countries still rely heavily on coal for energy irrespective of the estimated lifespan or current market trends. To ensure its sustainability, several developments have been made, including:

- The discovery of new reserves through ongoing and improved exploration activities along with advances in mining techniques which open previously inaccessible reserves
- Improvements in preparation and utilization to improve efficiency and reduce wastage and pollution

Fossil fuel reserves eventually run to completion and so it is essential that they are used as sustainably as possible with constant improvement into the efficient use thereof.

The South African coal market

South Africa (SA) houses the 9th largest coal reserve worldwide, with vast coalfields that are spread mostly across the north-eastern region of the country (IEA, 2014). Due to such a notable coal supply, the SA economy relies greatly on coal production and is accordingly listed as the seventh largest coal producer in the world succeeding China, America, India, Indonesia, Australia and Russia (WEC, 2017).

SA primarily utilizes coal as the main national source of energy, with an astounding 82% of the overall power requirements being provided by Eskom's coal-fired power stations (Chamber of Mines of SA, 2018). Various metallurgical applications such as steel, iron, cement and synthetic fuels production also rely heavily on coal as fuel and chemical reductant (IEA, 2011). Coal mining operations further makeup 17% of the total employment of SA citizens and is therefore the third largest employer in the mining sector (Stats SA, 2013). Coal, for these reasons, is a key source of energy and of paramount economic importance to South Africa. Coal also plays a key role in the SA export market as stipulated by the Department of Mineral Resources (2014). An average of 28% of the total coal produced is exported to the Middle East, Africa and Europe making South Africa the 6th largest global coal exporter (Chamber of Mines of SA, 2018). In 2016 South Africa exported by volume 28% of the coal produced worth R 50.5 billion (45% of the total sales). The remainder as utilized in-house attained a value of R 61.5 billion (Chamber of Mines of SA, 2018).

A large portion of the South African export coal is destined for India, making up approximately 45% of the coal export volumes (Chamber of Mines of SA, 2018). This may be problematic for South Africa given the recent allure for India to import from the USA (Prevost, 2018). Historically, Europe, especially the Netherlands, Belgium and the UK formed South Africa's main coal export market. This changed as a consequence of the Kyoto Protocol which sought to enforce a mandatory reduction in greenhouse gas emissions and thus, coal imports from these counties began to decline in 2007(Chamber of Mines of SA, 2018). China, also a major customer of South African coal export, has been forced to take measures in reducing the carbon dioxide emissions and this resulted in the closing of some coal mines or a severe decrease in the operating hours thereof (Chamber of Mines of SA, 2018). Even with the recent start-up of the coal mines situated in China, modifications into High-Efficiency Low Emission operation has been observed - with these requiring high-quality coal (Prevost, 2018). The export growth market for South African coal seems to include the countries situated in Asia, India Pakistan Malaysia, Taiwan, Bangladesh and possibly South Korea (Chamber of Mines of SA, 2018). Of note is that most of South Africa potential clients are on a big push towards implementing the HELE power plants that, as mentioned, require superior coal qualities with which some of the competitors are endowed (Chamber of Mines of SA, 2018). No scope for the export to countries belonging to the European Union is in place due to the environmental laws and some prospects of extending the export market to sub-Saharan Africa may prove difficult as a consequence of the dearth of investment and investment finance (Chamber of Mines of SA, 2008).

Coal in South Africa

Most coals mined in South Africa were formed in the Permian period and extend from sub-bituminous to anthracite in rank. These coals consist mostly of vitrain and grey durain lithotypes generally associated with vitrinite and inertinite macerals (SACPS, 2015). The South African coal seams that are of economic significance are generally mined in the Ecca and Beaufort groups of the Karoo basin (SACPS, 2015). This retro-foreland basin was created when tectonic movements resulted in a portion of the Gondwanaland super-continent to perpetually subside. Peat swamps developed within the basin and the forming coal deposits were thereafter affected by igneous intrusions associated with the rising of the Drakensberg. This provided the ideal conditions that ultimately led to the improved coal rank and the tendency for rank to increase from southwest to northeast regions (SACRM, 2011). There are a number of prominent coalfields occurring across the northeastern region of the country and are generally located in the Mpumalanga, Gauteng, Free State, Limpopo and KwaZulu-Natal regions. Figure 1 provides a map of South Africa with the major coalfields indicated in black.

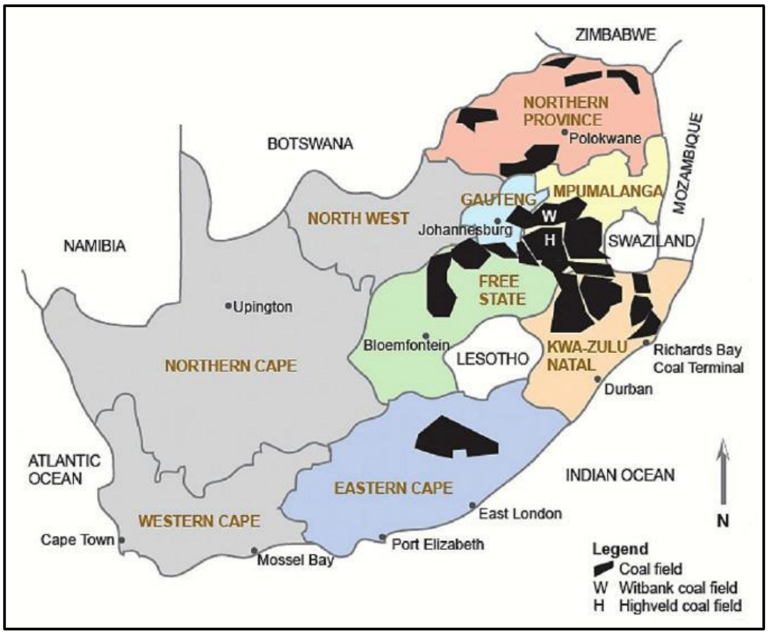

Figure 1: The main economic coalfields in South Africa (SACPS, 2015)

In Figure 1 the main coalfields and coal mining operations are visible. These coalfields are associated mainly with mud- and sandstone sediments (SACRM, 2011; Jeffrey, 2005). Approximately 70% of the remaining South African coal reserves are found within the Highveld, Witbank and Waterberg coalfields in Mpumalanga and Limpopo. The Witbank and Highveld coalfields in Mpumalanga are indicated with 'W' and 'H', respectively in Figure 1. Approximately 83% of the coal produced in South Africa is mined in the Mpumalanga area (Chamber of Mines of SA, 2018). These along with the Ermelo coalfield in Mpumalanga and the coalfields in the Free State and KwaZulu-Natal form the main coal mining areas in South Africa. A single large colliery is situated in the Waterberg coalfield in the western area of Limpopo and another smaller one is found near Soutpansberg towards the eastern border of Limpopo (SACRM, 2011). The main competing coal companies of South Africa are Anglo American, South 32, Universal Coal, Glencore, Sasol, Exxaro and Coal of Africa (Chamber of Mines of SA, 2018). There are also a number of smaller coal mining operations intermittent throughout the coalfields (Prevost, 2018).

South African coal products and utilization

Coal is used for three major applications in South Africa namely, coking in metallurgical processes, preparation of synthetic fuels and local electricity generation by Eskom but extends to the export market as well (Chamber of Mines of SA, 2018). Four coal products can, therefore, be categorized - metallurgical coal, synfuel coal, thermal coal and export coal generally reporting to grades A, B, C and D respectivley (SACRM, 2011). Each application requires coal of specific quality in terms of its unique properties such as calorific value, ash yield, volatile matter, sulphur present and moisture content. Table 2 provides the typical characteristics of South African ROM coal and coal products.

Table 2: Typical characteristics of South African coal products (SACRM, 2011)

Coal product	ROM coal	Grade A	Grade B	Grade C	Grade D
Ash value (%)	20 - 40	5.5 - 13	< 15	20 - 35	30 - 35
Sulphur content (%)	< 2	0.15 - 1.2	0.6 - 0.7	1 - 2	0.7 - 2
Calorific value MJ/kg	16 - 21	27 - 28.5	25 - 27	± 21	19 - 23

From Table 2 it is clear that coal preparation and improvement of the ROM quality may be essential to obtain the desired quality, depending on the product. The quality of thermal coal used in local electricity generation and synthetic fuel production is generally much lower than that used in metallurgical applications and for export. As a result, these coals can in many cases be utilized without beneficiation or only very little upgrading (Eberhard, 2011). The ROM coal grade and product specifications do not solely dictate the need for, and extent of beneficiation. The economic feasibility regarding operation should be considered and therefore many coal mining operations produce a dual product consisting of beneficiated coal for metallurgical and export purposes, and a middling product suitable for local consumption (SACRM, 2011). Figure 2 provides a diagram showing the relative distributions of saleable coal in South Africa.

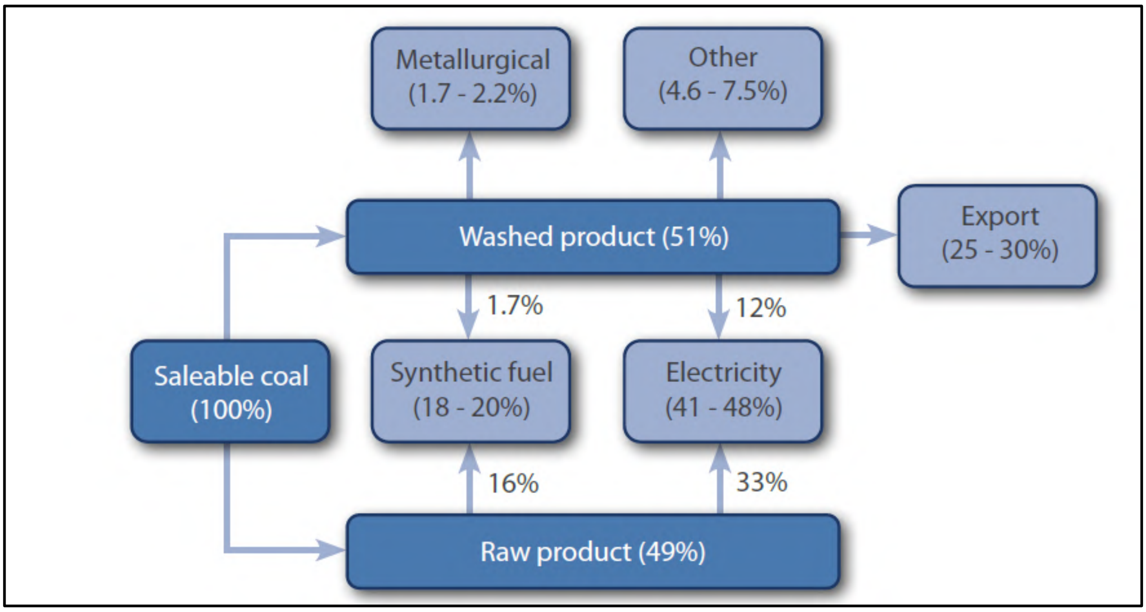

Figure 2: The relative distribution of saleable coal in South Africa (adapted from Prevost, 2010)

Figure 2 indicates that roughly 51% of the saleable coal in South Africa is beneficiated prior to use. Of that washed product, 1.7 - 2.2% is utilized in the metallurgical industry where 25 - 30% is exported. Some of this prepared product is utilized in the synfuel and electricity markets with the rest being provided by un-beneficiated coals. Extraction of high ash, or low grade, coal is, however, becoming increasingly frequent in South Africa with ash yield values as high as 40%$_{wt}$ being reported (Jeffrey, 2005). Thus, coal beneficiation is essential in ensuring a stable and sustainable coal feed for all relevant coal markets. The value of the coal in terms of global pricing may differ according to quality and is generally determined by the supply and demand. The benchmark price for domestic coal is set by Eskom (Chamber of Mines of SA, 2018). Further clear from Figure 2 is that a large portion (41 - 48%) of the coal in South Africa is produced for the thermal coal sector and roughly 18 - 20% is for the production of synthetic fuels. The export market is also quite large with 25 - 30% of the total prepared coal.

Current coal preparation practices

The desire to yield a coal product of the necessary quality for its intended purpose is proved imperative in the South African coal market. Beneficiation processes are thereby deemed vital in eliminating the sheer amount of extraneous and non-combustible matter in coal; in so avoiding the various issues related thereto (SACRM, 2011). Prior to beneficiation, it is necessary to reduce the coal to an appropriate size through comminution and screening. Moreover, since most coal mining utilizes water, the ROM coal may contain a certain amount of moisture. Typical values, mass distributions and moisture contents of the various size fractions as classified in South Africa are presented in Table 3.

Table 3: Typical classifications and characteristics for South African coal size fractions (SACRM, 2011)

Classification	Particle size (mm)	Mass distribution (% of total product)	Moisture content (AR $\%_{wt}$)
Coarse	12 - 250	61	5
Small	1 - 12	28	9
Fine	0.1 - 1	7	13
Ultra-fine	< 0.1	4	27

The various size fractions as described in Table 3 require different methods of upgrading in order to be successful. Most of the beneficiation plants in South Africa utilize wet coal beneficiation processes - specifically dense medium separation plants (SACRM, 2011). Figure 3 provides a generic block flow diagram of a typical water-based coal beneficiation plant in South Africa.

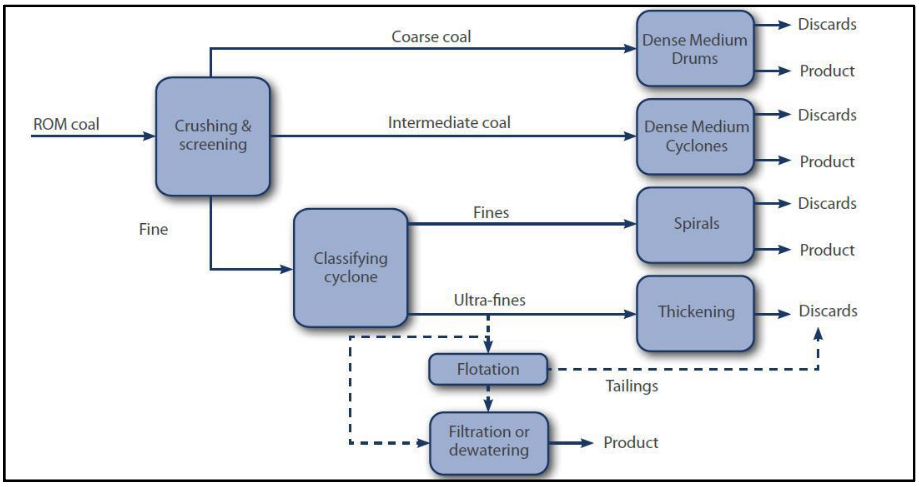

Figure 3: Generic block flow diagram of a typical water-based coal beneficiation plant in South Africa (SACRM, 2011)

The coarse coal is usually separated in a jig or dense medium bath or more recently in dense medium cyclones which are also used for beneficiation of the small coal fraction. Technologies that are considered feasible for the beneficiation of fine coal include the dense medium cyclones and spiral concentrators. The latter is more commonly implemented in South Africa due to the simple, low cost and reasonably efficient separation achieved. De-sliming of the spiral feed is often required in which the ultra-fine portion is removed by hydro-cyclones and transported to froth floatation cells. This is the only viable technique for successful beneficiation of the ultra-fine coal fraction. The resulting product, however, retains a high moisture content reducing its market value. The majority of the ultra-fine coal produced in preparation plants is still disposed of into slurry ponds or underground workings after dewatering (SACRM, 2011). Beneficiation of the fine and ultra-fine coal fractions provides some obvious benefits but presents a challenge in dewatering of the product. If effectively dewatered, the calorific value is improved, transport costs are reduced and fewer handling problems are experienced. The required moisture content of a conventional pulverised fuel boiler should not exceed $10\%_{wt}$. Centrifuges and filter presses are generally used to dewater the floatation and spiral product which may be subsequently blended with the coarser coal product (SACRM, 2011).

The coal preparation plants in South Africa have, over the years, successfully upgraded coal for various markets. These beneficiation methods may have to continue adapting to change especially when considering the declining ore grades, growing pressures to increase supply at reduced cost, efficient recovery of coal from the fine and ultra-fine fractions, pre-processing of ROM ore before beneficiation and re-processing of discards all with due consideration to the environment (SACRM, 2011). Some opportunities exist for optimising the performance of South African coal preparation plants in the face of these challenges (SACRM, 2011):

- Dry coal processing
- Simultaneous washing of coarse and small coal
- De-sliming, upgrading and agglomeration of fines (if needed) and ultra-fines
- De-watering of the fine and ultra-fine coal fractions

Many of these research areas are currently under review, investigation and development with dry coal processing being a topic that has received much attention. This is mostly due to the periodical and prolonged periods of drought experienced in South Africa making wet coal beneficiation possibly unsustainable.

The benefits of dry beneficiation for South Africa

South Africa is classified as a water-stressed country experiencing an average annual rainfall of 492 mm, which is well below the global average of 985 mm (Rand Water, 2017). Data obtained from The South African Weather Service (SAWS, 2017) indicates that the country experiences uneven distribution of rainfall accompanied by periods of severe drought. Notably dry conditions are observed in the north-eastern region which is known to consist of the coal-rich areas. Henceforth, rainfall and temperature forecasts provided by SAWS do not show desirable improvements with the likelihood of decreased rainfall anticipated in future. The predictions of continued decreasing rainfall especially in the coal-rich areas in SA gives rise to the importance of sustainable use of process water. Consequently, conventional wet processes may have to adapt to the availability of water. This placing much stress on the research has been undertaken into the alternative dry coal beneficiation methods in South Africa, and globally, in the hopes of yielding comparably high separation efficiencies, as obtained with wet techniques.

Dry processing provides some additional benefits to the South African coal market. Other than the obvious use of less water, dry processing yields a product (whether coarse, small or fine) that is dry and does not require any additional and possibly intricate and expensive de-watering procedures. Since most of the South African coal preparation plants utilize water-based separation methods, de-watering is essential to achieve the desired product calorific value (SACRM, 2011). Dry processing may, therefore, be a cost saving and time efficient option for South African coal processing plants. Some additional advantages that dry coal beneficiation may provide, include:

- Beneficiating reserves that are uneconomical to process by other means. This encompasses small, short term and remote reserves as well as discard recovery operations where the cost of wet processing may not validate the investment (Tomra, 2017; Manoucherchi, 2003).
- Beneficiating ROM ore in a pre-concentration step in order to remove coarse discard early in the process so that the cost of transporting and processing gangue is avoided (Tomra, 2017).
- Beneficiation (either as pre-concentration or final concentration) near or in the mine itself since the dry processes are modular with simple circuits and no extensive dewatering systems. The discard can then immediately be used as aggregate or backfill in the mine ensuring a cost-effective and efficient rehabilitation of the site (Manoucherchi, 2003).
- Beneficiating the previously discarded fine and ultra-fine coal since no extensive and expensive dewatering systems are required (Bada *et al.*, 2010).

Dry processing could clearly benefit the South African coal market but the advantages that it offers must be carefully weighed against the shortfalls for each individual application (De Korte, 2013). Dry coal processing generally yields a poorer separation efficiency than the conventional wet processing methods (Honaker *et al.*, 2008). Moreover, it proves difficult to control the product quality at specific density cut-points and may not be as efficient when processing coal with a significant amount of near dense material such as commonly found in coals originating in South Africa (De Korte, 2013).

Suitable dry processes for the South African coal market

In determining the processes most suitable for the South African coal market, it is necessary to consider the desired application and product specifications. In the coarser particle sizes (generally >6 mm), the *DE-XRT, All-Air Jig, FGX, ADMFB, SEP-AIR* and *coal winnower* may be utilized. These units are capable of delivering the following EPM and cut-point density values.

Table 4: Typical performance data for a dry coarse feed beneficiation processes

Technique	EPM	Cut-point density SG(D_{50})
DE-XRT	0.04 - 0.29	2.062
All-Air Jig	0.16 - 0.27	1.95 - 2.20
FGX	0.12 - 0.23	1.90 - 2.03
ADMFB	0.05 - 0.07	1.30 - 2.20
SEP-AIR	0.1 - 0.15	1.78 -1.90
Coal winnower	0.065 - 0.25	1.76 - 1.97

It is clear from the EPM values in Table 4 that an acceptable separation is possible. Given coal that does not require an extensive upgrade to reach product specification, any of the above-listed units could be implemented. Possible utilization would extend to the synfuel and thermal coal sectors requiring ash values ranging in 20 - 35% and 30 - 35%, respectively from a typical ROM coal ash value of 20 - 40%. Improved separation is also observed when processing easy to clean coals with little near dense material. In such a case any of the above units could be a viable dry beneficiation option and a coal product of higher quality may be obtained. South Africa is not known to have significant amounts of easily separable coals and therefore dry beneficiation currently does not show potential for the export and metallurgical markets. Much of the research undertaken in dry beneficiation has aimed at improving the separation efficiencies so as to yield a better product quality. This is crucial given the current and predicted water shortages experienced in South Africa and the effects thereof on the coal preparation industry.

Some other aspects of the performance of each unit may need to be considered. In comparison, the *DE-XRT, All-Air Jig* and *FGX* yield poorer separation efficiencies than the *ADFMB* and *SEP-AIR* units. As a result, the latter units attract more attention as probable processing techniques for South African coal. The coal winnower has only been tested on an experimental scale and may require further investigation and possible upscaling. It is still possible to implement the *DE-XRT*, *All-Air Jig* and *FGX* in certain applications including small or remote operations, re-processing a coarse discard or for pre-concentration of the feed to a preparation plant. Utilizing these may prove simple and cost-effective in comparison to erecting a wet separation plant, transporting the coal to a wet or dry preparation plant a distance away or processing the coal in the larger ADMFB and SEP-AIR plants. The *DE-XRT* can be adjusted to provide a sharp separation by increasing the sensitivity of selection but this comes at a disadvantage to the throughput. The *DE-XRT* shows potential in the specific cases of separating coal from torbanite and also pyritic sulphides. Given the strict feed preparation and presentation requirements for a *DE-XRT* sorter and that it shows better separation when separating the product and not the discard (as in the case of coal), sorting may not be as readily implemented for coal as it has been in the diamond industry.

With respect to the *ADMFB*, a sharp separation is possible for the coarse feed at a relatively high yield and a wide range of densities. The *SEP-AIR* shows slightly higher EPM values with a narrower range of cut-point densities. However, the issues associated with the additional use of magnetite as a dense medium material in the *ADMFB* proves this unit to be complicated, costly and therefore unfeasible for the South African coal market. The SEP-AIR does not require additional medium and can also be utilized for a fine coal feed (1 - 6 mm). This provides the opportunity to beneficiate the undersize coal that is generally removed from the feed and either discarded or added to the product as un-beneficiated. By this, some of the difficulty in controlling the product quality is abated due to the upgrading of the fine coal fraction. Consequentially, this unit additionally addresses the opportunity of processing coarse and fine particulates simultaneously. Some investigation has steered into the beneficiation of the fine coal fraction using air tables, the winnowing unit, an adapted ADMFB and a reflux classifier - and the ultra-fine coal fraction using rare earth roll magnetic separators or tribo-electrostatic separators possibly in combination with microwave heating. These show a separation that is comparable to that achieved by the units for a coarse coal feed but may require some further attention and upscaling studies.

The future of dry coal beneficiation in South Africa

Coal remains of paramount importance to South Africa - providing approximately 860 478 relatively well paid and stable jobs (Prevost, 2018). Furthermore, it is abundant and affordable and supplies most of South Africa's energy requirements along with considerable income through export (Prevost, 2018). This comes despite the rapid increase in renewable energy sources with these sustaining the exponential increase in energy demand while the contribution from coal remains steady and not likely to change in the near term (Prevost, 2018). The coal production in South Africa is stagnant and not increasing due to the low incentive and lack of capital to implement new coal projects (Prevost, 2018). It is expected that this production rate will soon decline drastically due to the nearing depletion in some of the older and larger reserves (Coal Cliff in Prevost, 2018). This may also force the utilization of significantly lower grade coals (Prevost, 2018). Moreover, some companies such as Anglo American and South 32 are scaling down their presence in South Africa as a result of Eskom's demand for 51% empowerment ownership from coal suppliers (Prevost, 2018). Clearly, some production problems may arise from this decision but new opportunities emerge as South 32 intends on erecting a stand-alone thermal coal business which supplies Eskom and the export market (Prevost, 2013). Some trends in the global market may affect the future of coal in South Africa. With the reduced demand for South African coal in Europe, India and China it may seem that a larger domestic market emerges (Prevost, 2018). Exports may never recover the allure it had in the past and due to the lower export tonnages more low-ash and, high-ash coals will be used inland at higher prices (similar to those of export) (Prevost, 2018).

Currently, most South African collieries are merely attempting to optimize their coal production in order to supply the inland or export markets depending on revenue (Prevost, 2018). Some reserves, such as the Waterberg coalfield, hold significant potential but cannot be exploited until the infrastructure is significantly improved (Prevost, 2018). These potentially new reserves are required in order to sustain the demand from Eskom and independent power producers such as Anglo American and South 32 (Prevost, 2018). It is unlikely that the export market will grow until the present coal oversupply and high prices change (Prevost, 2018). This establishes the need for a shift toward the domestic coal market in South Africa and focus is to be placed on the thermal and synthetic fuels sectors.

When considering the above and the current environmental trends regarding rainfall and water scarcity in South Africa, dry coal processing provides some measure of a solution. The simple and modular plant design allows for easy implementation and relocation making it possible to erect such plants in or near the various small reserves and also remote and under-developed areas such as the Waterberg coalfield.

It is in no doubt that South Africa may soon be forced to implement dry processing techniques for coal beneficiation given the declining reserves and consideration of the environment. Some small dry coal washing operations have already been undertaken in South Africa with the *FGX* unit situated in Klipfontein, Mpumalanga. This plant upgrades coal obtained from a small coalfield on site and supplies a thermal coal product to Eskom with an expected lifespan of 5 years (Cowan, personal communication 28 November 2018).

It may be impossible to completely eliminate wet coal processing due to the sharp separation efficiency and large yields obtainable; making it ideal to supply the large demand. Dry coal processing can, however, solve the water and infrastructure related issues that the South African coal preparation industry now faces. Implementing these processes for the new coal mining operations that are especially remote and under-developed, such as those in Waterberg, may be necessary. Similarly, small operations or expenasions can benefit from simple plant design and low-cost factor. It may also be useful to implement these in conjunction with wet processes as a pre-concentration step which may significantly reduce the size and throughput of the wet plants - so that it utilizes less water or reagents. Alternatively, the same production can be met but with a vastly improved coal feed and no processing of unnecessary gangue. Dry coal processing may also provide a solution for the upgrading of the coal fines so as to eliminate the need for extensive and expensive dewatering processes post beneficiation.

As already mentioned, the *SEP-AIR* pneumatic concentration complex proves most attractive for implementation in South Africa due to its fair separation efficiency and wide particle size processing range. It is predicted that this unit may sufficiently upgrade coal to a thermal or syn-fuel standard at relatively large throughputs (45 - 220 tph). The South African coal industry may well see many similar units processing in the new operations or expansions for smaller and remote regions in the near future. Some application for the less effective All Air Jig and FGX in the small coal mines is also expected. It is further believed that investigation into the fines dry processing will continue and that a plan to implement these dry processes, whether alone or in combination with the current plants, will soon develop.

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References

Bada, S.O., Falcon, R.M.S. and Falcon, L.M. 2010. The potential of electrostatic separation in the upgrading of South African fine coal prior to utilization-a review. *The Journal of the Southern African Institute of Mining and Metallurgy, 10:691-702.*

British Petroleum. 2018. BP Energy Outlook 2018 Edition. BP Energy economics. Accessed from: https://www.bp.com > energy-economics. Date of access 6 July 2018.

Chamber of mines of South Africa. 2018. Coal strategy 2018: National coal strategy for South Africa. Accessed from: https://www.chamberofmines.org.za. Date of access: 12 Jan 2019.

De Korte, J.G. 2013. Dry processing versus dense medium processing for preparing thermal coal. CSIR (Council for Scientific and Industrial Research). Pretoria, South Africa.

Department of Energy, 2017. Coal resource. Retrieved from http://www.energy.gov.za/files/coal_frame.html. Date of access: 11 May 2017.

Department of Mineral Resources, 2014. South African Yearbook. In: Johannesburg, South Africa: s.n., pp. 301-311.

Eberhard, A. 2011. The future of South African coal: Market, investment, and policy challenges. Accessed from http://iisdb.stanford.edu/pubs/23082/WP_100_Eberhard_Future_of_South_African_Coal.pdf. Date of access: 24 Feb. 2016.

Honaker, R.Q., Saracoglu, M., Thompson, E., Bratton, R., Luttrell, G.H. & Richardson, V. 2008. Upgrading coal using a pneumatic density-based separator. *International Journal of Coal Preparation and Utilization*, 28 (1): 51-67.

International Energy Agency (IEA). 2011. Power generation from coal. Retrieved from https://www.iea.org/publications/freepublications/publication/Power_Generation_from_Coal2011.pdf Date of access: 24 Feb. 2016.

International Energy Agency (IEA). 2014. Medium-term coal market report 2014 factsheet. https://www.iea.org/media/news/2014/press/141215_MTCMR2014_Factsheet.pdf Date of access: 24 Feb. 2016.

Jeffrey, L. S. 2005. Characterization of coal resources of South Africa. *The Journal of the Southern African Institute of Mining and Metallurgy, 105*: 95–102.

Manoucherhi, H.R. 2003. Sorting: Possibilities, limitations and future. Northland Oretech ConsultingCo. Docentvagen 26, SE-977 52, Sweden.

Prevost, X. (2010) Coal statistics and opportunities for junior coal miners. Wood Mackenzie Coal Consulting, Pretoria. Unpublished.

Prevost, X. PowerPoint presentation (29 August 2018). SA Coal Marketing. Southern African Coal Processing Society Coal Metallurgists and Plant Operators Workshop. Secunda, South Africa.

Puko, T. 2018. Ohio utility seeks Trump's help for its struggling plants. *The Wall Street Journal*, published 29 March 2018. Accessed from: https://www.marketwatch.com. Date of access: 1 Sep 2018.

Rand water. 2017. Water Wise. Accessed from: http://www.waterwise.co.za/site/water/environment/situation.html. Date of access: 11 May 2017.

International Energy Agency (IEA). 2018. Market report series: Coal 2018. Accessed from: https://www.iea.org. Date of access: 24 Feb 2018.

SACRM (South African Coal Roadmap). 2011. Overview of the South African coal value chain. Johannesburg. Accessed from: http://www.sanedi.org.za/coal-roadmap/.Date of access: 25 April 2018.

SACPS (South African Coal Processing Society). 2015. *Coal Preparation in South Africa.* Pietermaritzburg: Natal witness commercial printers.

SAWS (South African Weather Service). 2017. Drought monitoring March 2017. Retrieved from http://www.weathersa.co.za/images/climate/pdf/CLS-CI-Drought%20Monitoring-2017-04.pdf Date accessed: 11 May 2017.

Stats SA, 2013. The importance of coal. *Mining Industry (Report No.20-01-02).*

Tomra. 2017 (May). Ore sorting. Powerpoint presentation at AusIMM, Australia.

U.S. Energy Information Administration (EIA). 2017. International Energy Outlook 2017. U.S. Energy Information Administration. Accessed from: http//:www.eia.gov/ieo. Date of access 26 March 2018.

World Coal Institute (WCI). 2009. The Coal Resource: A Comprehensive Overview of Coal. Accessed from: https://www.worldcoal.org/sites/default/files/coal_resource_overview_of_coal_report (03_06_2009).pdf Date of access: 25 Feb. 2016.

World Energy Council. 2017. World Energy Council. Accessed from: https://www.worldenergy.org/data/resources Date of access: 11 May 2017.

International Energy Agency (IEA). 2017. Coal 2018. Accessed from: https://www.iea.org. Date of access: 20 Feb 2018.