International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca
IJGE 2018 **4**(**3**): 127-132
Available at http://ojs.library.dal.ca/ijge
Research and Development and Industry

Mining of the Waterberg - a Unique Deposit Requiring Innovative Solutions

Chabedi Kelello[1*], Mhlongo Sifiso[2]
[1] Department School of Mining Engineering, University of the Witwatersrand, Johannesburg, South Africa
[2] Exxaro Grootegeluk Coal Mine, Lephalale Limpopo, South Africa

Abstract: The Waterberg coalfield is a resource for the future contribution of energy in South Africa and has been marginally exploited to date. The coal deposit is technically unique and challenging. The carbonaceous nature of the overburden, interburden, the coal intercalations and discard makes it prone to spontaneous combustion. The coal has a high percentage of ash and low yields after beneficiation. Another unique feature of this coalfield is that it is a multi-seam coal deposit with a total of 13 benches occurring over a total thickness of 110m. Only one large open pit mine is currently in operation at the Grootegeluk Colliery despite the size of the resource. The mine has innovatively exploited the coal deposit profitability despite these challenges. Grootegeluk Colliery produces about 86 million tonnes ex-pit. The ROM produced in 2015 was about 54 million tonnes per annum (Mtpa) and the total waste produced was about 32 Mtpa making it one of the largest open pits in the history of South Africa. The paper discusses the state of the current mining and beneficiation techniques being used at the mine to exploit this vast reserve of the Waterberg coalfield which is the future coal supply of South Africa.

Keywords: Waterberg coalfield, Grootegeluk, open pit, spontaneous combustion, coal

1 Introduction

This paper discusses the innovative mining of the Waterberg coalfield at the Grootegeluk open-pit mine. Specifically the mining of the waste and coal using thirteen different benches at Grootegeluk is discussed with an emphasis on the separate mining of the Upper and Middle Ecca benches. The emphasis is on the quantity and quality of the coal produced and the different markets supplied in order to make the mine profitable, low cost and sustainable. The latter part of the paper focuses on the equipment used and the eight beneficiation plants unique to the Grootegeluk complex. Finally, spontaneous combustion problems and how to combat those problems in an open-pit environment where there is carbonaceous coal and shale is briefly discussed.

2 Current Mining in the Waterberg

Grootegeluk coal mine is the only operating mine in the Waterberg, and is an open- pit mine situated in the shallow, western part of the Waterberg Coalfield. The mine was commissioned in 1980 to supply coal to ESKOM's Matimba and lately the Medupi power stations and a blend coking coal to ISCOR now (Mittal Steel) as a bi-product. Matimba and Medupi are the largest direct dry-cooling power station in the world and have declared reserves of more than 20 years minimum. The annual send-out power of the Matimba power station is approximately 24 000 gigawatt hours (ESKOM 2013) and is expected to generate 4000MW while Medupi power station is designed to generate 4800 MW (ESKOM 2014). The blended coking coal is mined mostly from the bright coal of the Upper Ecca (Benches 2 to 4). The intercalated nature of coal and shales in the Upper Zones prevent any form of selective mining. The only feasible and economic way of mining the Grootegeluk Formation is through opencast benches. The benches are designed in such a way that they allow the entire seam in the selected zone to be mined according to geological markings (Dreyer 1994).

Figure 1 indicates how mining of overburden, interburden and coal is carried out on different benches for saleable product and waste. There are a total of 13 benches defined at the mine. Of the 13 benches three are sub-divided into A and B units. These are benches 1, 7 and 9. Bench 1A, 1B and 7A are waste units, while Bench 7B, 9A and 9B are coal units. 9 of the 13 benches are mining coal and the remainder are mining waste.

Four benches numbered 2 to 5 mine coal in the Upper Ecca or Grootegeluk formation. These benches correspond to Zones 5 to 11 numbered from 11 at the top and 5 at the bottom. The coal from Benches 2 to 4 contains bright coking coal with high vitrinite content.

The yield of this bright coal is between 8 to15 per cent because of the large proportions of shale intercalations. The shale intercalations are typically as high as 60 per cent because of non - selective mining. The rest of the coal is middlings for the power station at a yield of 30 to 40 per

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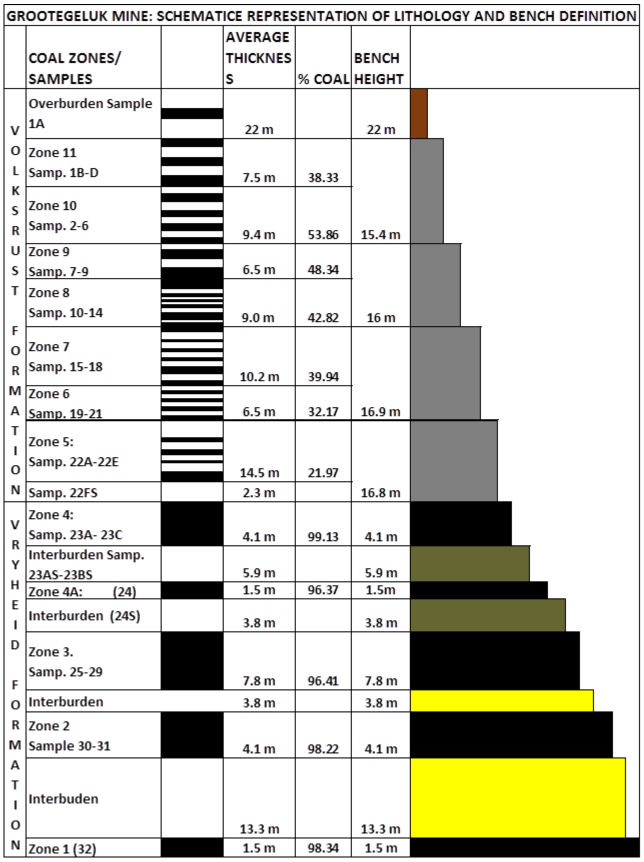
* Corresponding Author: Chabedi Kelello, Email: kelello.chabedi@wits.ac.za, phone: +27 83 699 1869

DOI: 10.15273/ijge.2018.03.021

cent. Due to the high proportion of deleterious shale in the coal from the Upper Ecca, it requires a high density de - stoning step to remove the bulk of the non-carbonaceous material (De Korte 2010).



GROOTEGELUK MINE: SCHEMATICE REPRESENTATION OF LITHOLOGY AND BENCH DEFINITION

	COAL ZONES/ SAMPLES	AVERAGE THICKNESS	% COAL	BENCH HEIGHT
VOLKSRUST FORMATION	Overburden Sample 1A	22 m		22 m
	Zone 11 Samp. 1B-D	7.5 m	38.33	15.4 m
	Zone 10 Samp. 2-6	9.4 m	53.86	
	Zone 9 Samp. 7-9	6.5 m	48.34	16 m
	Zone 8 Samp. 10-14	9.0 m	42.82	
	Zone 7 Samp. 15-18	10.2 m	39.94	16.9 m
	Zone 6 Samp. 19-21	6.5 m	32.17	
	Zone 5: Samp. 22A-22E	14.5 m	21.97	16.8 m
	Samp. 22FS	2.3 m		
VRYHEID FORMATION	Zone 4: Samp. 23A- 23C	4.1 m	99.13	4.1 m
	Interburden Samp. 23AS-23BS	5.9 m		5.9 m
	Zone 4A: (24)	1.5 m	96.37	1.5m
	Interburden (24S)	3.8 m		3.8 m
	Zone 3. Samp. 25-29	7.8 m	96.41	7.8 m
	Interburden	3.8 m		3.8 m
	Zone 2 Sample 30-31	4.1 m	98.22	4.1 m
	Interbuden	13.3 m		13.3 m
	Zone 1 (32)	1.5 m	98.34	1.5 m

Figure 1 A schematic diagram of the lithology and bench definitions of the Upper and Middle Ecca at Grootegeluk (Adapted from EXXARO Resources Ltd 2015)

The geological structure of the Upper Zone formation, is less complicated and the coal is generally acceptable for blend coking coal characteristics. Although, bench 5 is part of the Upper Ecca formation no mining of coking coal takes place on this bench because of high phosphorous content. Instead the coal from this bench is currently mined to yield a product suitable for combustion by ESKOM (De Korte 1994).

The lower benches numbered 6 to 13 (i.e. 6, 7B, 9, 10, 11 and 13) are used to mine coal and benches 7A, 8, 10 and 12 are used to mine interburden. The coal in the Middle Ecca is mostly dull and of poorer quality when compared to that of the Upper Ecca. Bench 6, 7B and 9A are mined for the power station while Benches 9B and 11are exploited for power station and metallurgical coal. The coal benches are separated from each other by prominent sandstone, siltstone and shale interlayers.

The coal mined for metallurgical purposes is used as a semi coking coal, as well as to produce CHAR. CHAR is coal that is produced by a carbonization process at low temperatures resulting in a solid residue high in carbon and can also be used in the COREX process. CHAR can also be described as devolatilised coal used as a reductant in the ferro-alloy industries. COREX is a direct reduction process to make iron where non-coking coal is used to reduce iron ore to iron.

In summary, there are different approaches to beneficiating the Volksrust Formation and the Vryheid Formation. The Volksrust Formation is beneficiated for semi-soft coking coal and thermal coal while the Vryheid Formation is beneficiated mostly for thermal coal (De Korte 2010).

Bench 13 is not mined at present because of a thick interburden Bench 12 which must be removed to access it. Furthermore the coal in this bench is thin and therefore uneconomic. The thickness of the coal is about 1.5 metres. The sandstone above bench 13 is about 13 m thick as shown in Figure 1. The geological contacts of the coal zones coincide with the zone boundaries and make the benches to be between 15 and 17 m in height in benches 2 to 5. Thickness in the Vryheid formation vary between 1.5 m and 7.8 m. The bench heights make it possible to mine the zones easily with opencast machines such as trucks and shovels (Dreyer 1994).

3 Mining of the Different Benches

The mining of all the benches is described in detail below in order to give an understanding of how the thick coal zones of 110m package of the Waterberg stratigraphy are presently exploited by open pit mining. First, it is important to note that benches that correspond to coal zones are selected and that the height of these benches range from 1.5 m at the lowest to a maximum of about 16 m. The height of the benches also takes into account the size of available mining machinery. The benches start from the top to the bottom as opposed to the coal zones that start from the bottom upwards. In general the top benches (1-5) are mined with a combination of a rope shovel and bigger trucks as explained later on in Tables 1 and 2 respectively.

The first bench (Bench 1) is an overburden bench. It is estimated to be about 1.5m at the lowest to a maximum of - 20 m high in the western part of the coalfield and the overburden has a density of about 2.5 tonnes per cubic metre (t/m^3). At this depth the stripping ratio is low and acceptable for open-pit mining. One can expect a lot of waste stripping and topsoil stripping on this bench as is typical of any surface mine.

The second bench (Bench 2) corresponds to Zones 11 and 10 and it is the first coaling bench which is estimated to be about 13.5 m high and has an average coal density of roughly 1.74 t/m^3.

The next benches are also coaling benches i.e. benches 3 and 4. These benches are about 16m in height and have a coal density of about 1.86 t/m^3. Bench 3 corresponds to zones 9 and 8. Bench 4 corresponds to zones 7 and 6.

Bench 5 corresponds to Zone 5 and is also a coaling bench which is about 16.7 m high with a density of 1.88t/m^3. The first five benches discussed are found in the Upper Ecca and therefore have a mixture of bright coal with high vitrinite content by South African standards. The layers of bright coal are interbedded with carbonaceous mudstone (De Korte 1994).

In general the lower benches (6-13) are mined with a combination of front end loaders, hydraulic shovels and smaller trucks as explained in detail in Tables 1 and 2 respectively. The benches that follow form part of the Middle Ecca or the Vryheid Formation which is composed mostly of dull coal, sandstone and carbonaceous shale. Bench 6 corresponds to Zone 4 and is a coaling bench that is about 4 m high with a density of 1.65 t/m^3. The coaling benches of the Middle Ecca have an average thickness above 4m except Bench 7B which is less than 2m.

Bench 7 is divided into a waste and a coaling bench. Consequently, Bench 7A is an interburden bench which is about 4.3m with a density of 2.21 t/m^3 and Bench 7B corresponds to Zone 4A and is a coaling bench where the seam is about 1.5 m thick and has a density of 1.80 t/m^3.

Bench 8 is a waste bench which is about 4.3m high with a density of 2.45 t/m^3 and Bench 9 corresponds to Zone 3 and is a coaling bench which is about 7.82 m high. This coaling zone is mined in two benches i.e. Bench 9A and 9B with densities of 1.64 t/m^3 and 1.53 t/m^3.

Bench 10 is an interburden bench, mining sandstone and is about 1.4m high with a density of 2.5 t/m^3 and Bench 11 correspond to zone 2 and is coaling bench which is on average estimated to be 3.73m with a relative density of 1.52 t/m^3.

Bench 12 is an interburden bench and is on average estimated to be 3.85m with a density of 2.5t/m^3. Bench 13 corresponds to Zone 1 and is a coaling bench which is estimated to have a seam thickness of 1.5m with a density of 1.52 t/m^3. Figure 1 gives a comprehensive summary of the benches in terms of their numbering, percentage coal in each bench or zone, lithology, bench height and density.

4 Mining Equipment at Grootegeluk Mine

Mining at Grootegeluk open pit mine is done using the truck and shovel method. In general, the overburden and inter-burden are mined by electric shovels and the coal is mined primarily by all three types of primary mining equipment (hydraulic shovel, rope shovel and front end shovels). There is a combination of Komatsu PC 4000 which are front end loaders or back hoe and Komatsu PC 5500 front end loader, Taiyuan Heavy Industry (TZ) rope shovels, CAT 994 wheel loaders and LeTourneau electric-drive wheel loader. The sizes of front end loaders and electric shovel and the tonnes per hour mined by each shovel are indicated in Table 1.

Table 1 Types of Shovels (EXXARO Resources Ltd 2015)

Type of shovel	Typical tonnes per hour
CAT 994 Wheel Loader	1200
LeTourneau Wheel Loader	3200
PC 4000 Back Hoe	2100
PC 4000 Front End Loader	2200
PC 5000 Front End Loader	2200
TZ Rope Shovel	4200

According to the information gathered during a mine visit there are over 50 haul trucks on the mine in total. The fleet is composed of Komatsu 730E’s, Hitachi EH 3500’s, Hitachi EH 4000’s and Euclids 3500. The type of trucks and payload expected are given in Table 2.

Table 2 Types of Trucks (EXXARO Resources Ltd 2015)

Types of trucks	Typical payload
Komatsu 730E	180
Euclid EH3500	180
Euclid EH4000	220

The bigger trucks which are the Hitachi EH 4000’s carry the most payload and consequently consume more diesel. However, it should be noted that the productivity of the trucks depends on the distance travelled to and from the tip and is a function of how the dispatcher allocates trucks to the different ramps. The expected productivity of the Komatsu 730E is comparable and very similar to that of the Hitachi EH 3500. All trucks are equipped with electric wheel motors. They therefore use both diesel and electricity. Main haulage roads have pantograph lines on which the trucks connect to save diesel on the uphill road to the beneficiation plants. During the travel on electricity the trucks can achieve a minimum speed of 24 km/h. Hitachi EH 4000’s trucks can travel faster than the other trucks as they have AC drive motors while the rest have DC drive motors.

The current mining depth is about 130m with an average stripping ratio of 0.49 m^3/t. The stripping ratio is the ratio of the volume of the overburden or waste mined to the volume of the tonnes of coal mined in most surface mines is usually between 6 and 8 but due to the thickness of the coal in Grootegeluk mine the stripping ratio is low. Other supporting equipment include drills, dozers (rubber and tyred), graders and water tankers are provided to make mining.

5 Quality and Quantity of Coal Mined

In 2015, the mine produced 86 million tonnes ex-pit. The ROM produced was 54 million tonnes per annum (Mtpa) and the total waste produced was 32 Mtpa. The breakdown of the waste produced is 23 Mtpa overburden and 9 Mtpa of interburden. The tonnes produced by the plant after the coal was washed were about 27 Mtpa of sales and therefore 27Mtpa was discard (EXXARO Resources Ltd 2015).

The final product produced by the plant is distributed as 85% for Matimba power station, about 8.5 % for the semi - soft coking coal and 6 % for the metallurgical coal.

6 Beneficiation

There are different approaches for beneficiation of the coal for the Upper section or Volksrust and the Lower section or Vryheid Formation. The Upper section is washed mainly for coking coal and thermal coal whereas the lower section is beneficiated mainly for thermal coal. The Volkrust

Formation contains a large proportion of impurities typically approximately 60%. This necessitates beneficiation of the raw coal. The beneficiated bright coal product, by virtue of its high vitrinite content and other properties, is suitable as a blend coking coal (De Korte 1994, 2010).

The coal from the Upper Ecca requires high capacity processing plants and the coal contains high amounts of dense material. The coal requires very efficient separation process that is the dense medium process and has to be crushed to a small top size (about 15mm) to liberate the coking fraction. The coal is also very friable and generates a lot of fines during handling and crushing. Therefore effective fine coal processing techniques are required. After beneficiation of the coal there is a need to dewater the products.

The Upper section, employs two stages of preparation on benches 2, 3 and 4. A first, high density separation stage is employed to remove the impurities from the raw coal. The float product from the first-stage processing is re-treated at a lower relative density to yield a blend coking coal containing approximately 10% ash and a middling product containing approximately 35% ash. The blend coking coal is utilized by Mittal Steel in the production of metallurgical coke, while the middling fraction is used for power generation at the nearby Matimba power station (De Korte 1994).

The Lower section consists of five coal seams on Benches 6-11 with the exception of Benches 7A, 8, 10 and 12 which are interburden benches. As stated before some of the coal especially benches 9A and 11 are suited for use in the thermal market in the raw state meaning that no beneficiation takes place. This coal requires crushing and screening only. Coal from Bench 7B requires high density beneficiation to lower the ash content. Coal from Benches 9A and 11 are processed to produce a pulverized coal injection (PCI) product. Bench 13 is very thin and considered uneconomic at present.

In summary the mine produces three products, namely semi soft coking coal, power station (steam or thermal) coal and metallurgical coal. Semi soft coking coal is produced mainly from the Upper Ecca. Thermal coal is produced mainly from the Middle Ecca and Upper Ecca. Metallurgical coal i.e. PCI is produced from the Middle Ecca.

In general raw coal at Grootegeluk mine is of high ash content and as a result, large coal beneficiation plants are needed to meet the production targets for both the metallurgical and thermal markets. For this reason 10 plants have been erected since 1980 to produce the required quantities of coal (De Korte 2010).

7 Discussion of the Grootegeluk Beneficiation Plants

Coal from the Waterberg coalfield is beneficiated differently to Witbank coalfield i.e. it requires ten large, separate plants to beneficiate the coal in order to meet the customer requirements as shown in Figure 2.

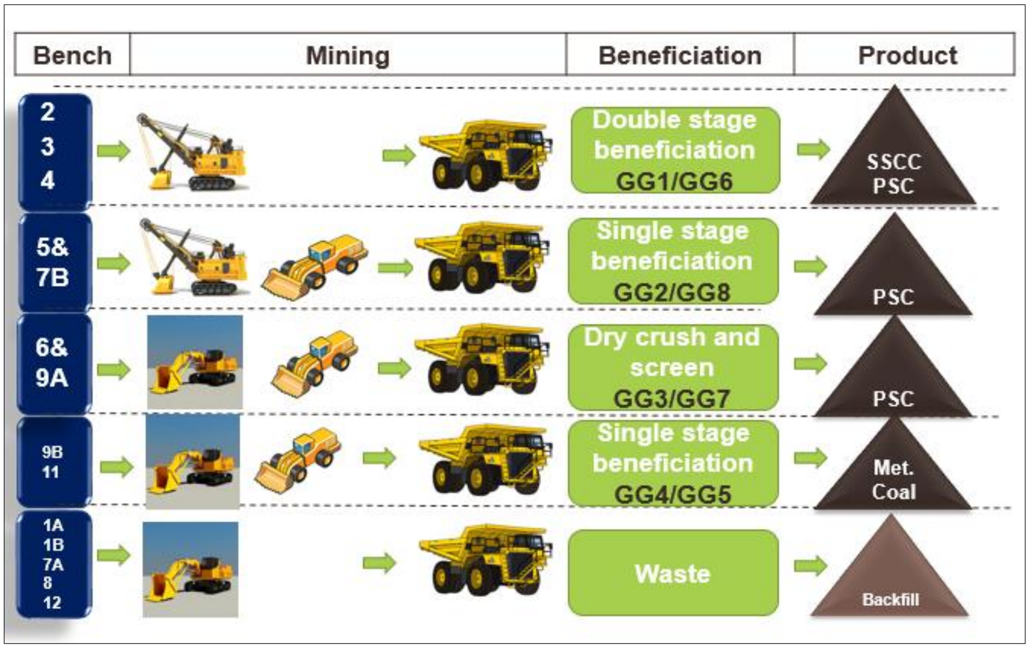


Figure 2 Material Flow and mining equipment of the different zones (EXXARO Resources Ltd 2015)

Grootegeluk 1 (GG1) produces semi - soft coking and steam coal as middlings. The plant is a two stage wash plant with low phosphorous percentages and high ROGA and swell characteristics for coking properties. The ROGA index is an indication of the caking capacity of the coal (MineSkill Australia 2010). The coal for this plant is supplied from benches two to four.

Grootegeluk 2 (GG2) is a single wash plant that produces steam coal for the power station from benches two to four at a relative density of 1.8. The coal requires high density beneficiation to lower the ash content (De Korte 2010).

Grootegeluk 3 (GG3) is a crush and screen plant which takes coal from Zone 4 or Bench 6 with a calorific value of 20.5 per cent and ash content of about 35 per cent and produce only steam coal for the Matimba Power Station. As discussed before this is dull coal but the coal is suitable to be used at the power station as raw feed thus saving on the washing costs.

Grootegeluk 4 and 5 (GG4 and GG5) produce pulverised injection (PCI) or duff with a high calorific value in the range of about 27.4 MJ per kilogram and ash of less than 17 per cent and steam coal. They also have a low phosphorous content to control emissions that are harmful to the environment. This coal produces CHAR which is used in the specialised steel industry. The coal for these two plants is mined from benches 9 and 11.

Grootegeluk 6 (GG6) is a new plant that produces semi soft coking coal and middlings for the power station also from benches 2 to 4.

Grootegeluk 7 and 8 (GG7 and GG8 are crush and screen plants that produces coal directly for Matimba and Medupi power stations.

Grootegeluk 10 (GG10) is a double stage wash plant that produces coal for the export or metallurgical purposes and midlings for the power station form benches 9A and 9B.

The beneficiation plants that handle the coal from the various mining benches are shown in Figure 2 (EXXARO Resources Ltd 2015).

8 Spontaneous Combustion

Grootegeluk Mine coal and waste material have a propensity for spontaneous combustion because of the rank of the coal amongst other factors and the carbonaceous nature of the overburden and interburden. The ROM has a yield of about 50 per cent, implying that half of the production that the mine produces ends up as discard after the beneficiation process. The plant discards have a high propensity for spontaneous combustion. The inter-burden material is also prone to spontaneous combustion due to its carbonaceous nature. The problem associated with this large quantity of waste is safe storage and disposal in a way that will prevent the occurrences of fires in the pit (Adamski 2003). The discard materials that need to be handled are mixtures of discards from various plants and waste from benches with unknown properties. Thorough knowledge of the chemical and physical properties of all the different materials and mixtures was considered to be a pre-requisite for the design of safe waste dumps/heaps (Adamski 2003). Through research it was discovered that the Grootegeluk Mine plant discards are coarse, burn easily and are very reactive. The most dangerous combination of these was a mixture of coarse and fine materials which represented Grootegeluk Mine pit waste (interburden from Benches 7 and 8).

According to Adamski in his PhD thesis (Adamski 2003), some of the above findings were recommended by Professor Glasser, a chemical engineer and one of the experts in the field of spontaneous combustion. Glasser recommended crushing and segregating material before stacking which will result in placing finer material on top of coarse material (Glasser 1983). This will effectively allow the thin, low permeable material to block air transportation. He further recommended that to minimise permeability that the dumps surface and slopes be compacted at Grootegeluk. Finally, Glasser recommended that a thin layer of middlings be stacked over the whole dump. However, the harsh climate of sun, rain and wind made for a very maintenance intensive process to ensure oxygen did not gain entry through cracks in the surface, compacted layer. Research and application of the above research by Adamski at Grootegeluk led to the conclusion that the thin layer of middlings, due to high reactivity and low permeability, if compacted, will be able to prevent oxygen from entering into the waste dumps due to two reasons.

Firstly, the thin, low permeable layer of middlings would absorb oxygen and secondly due to low permeability it would restrict the airflow into the dumps (Adamski 2003). Grootegeluk mine needed a safe method of disposing and storing the discard material from the plant i.e. middlings and the waste material produced form the pit. After much research and experimentation by Adamski - a backfill method that involves stacking the material in the pit into – prebuilt and sealed compartments was found to be a solution for the Grootegeluk spontaneous combustion problem. This method took into account aspects such as the critical time (8 weeks for slopes and 3 months for surface areas) that reactive material can be exposed to air. The critical time determined the stacking rate as well as the dimensions of the backfilling compartments. To maintain the constant stacking rate the compartments width had to be fixed.

The 110m deep pit was to backfilled to the natural ground level. The backfilling was done using four levels. The first level will contain interburden material. The second and third levels contained plant discards while the fourth-sealing level contained material with a layer of about 1m thick top-rehabilitated topsoil. The heights of the various levels were subsequently changed due to changes in production rates, to allow a safe stacking rate. The effect of backfilling in the pit was not only to place discards from the plants but also to use inert material and pit waste that would otherwise need to be hauled out of the pit (Adamski 2003).

9 Conclusions

The Waterberg coalfield is a technically challenging coal deposit to exploit because of its multi-seam nature, propensity for spontaneous combustion and coal quality characterised by high ash content. However, Grootegeluk Colliery has managed to overcome these challenges and is one of the biggest open-pits in the world and mines about 86 million tonnes of coal and 32 million tonnes of waste from the pit to meet the production requirements at a low cost. The Run of Mine coal produced in 2015 was about 54 Million tonnes per annum for the Medupi and Matimba power stations. About 50% of the ROM is produced as waste which is prone to spontaneous combustion and has to be managed carefully in the pit. The mine operates a large fleet of haul trucks and a combination of shovels and front end loaders to produce coal and waste including discards. In order to meet their production requirements coal and waste from the 13 benches has to be mined meticulously. Grootegeluk has ten one of the largest plants in South Africa producing three types of products i.e. semi-soft coking coal, steam coal and metallurgical coal in order to offset the mining costs and meet the customer requirements. The mine has experienced and successfully solved the problem of spontaneous combustion which is a major problem for surface coal mines in South Africa.

Acknowledgement

This research project is made possible through the support of Exxaro Resources Limited and the School of Mining Engineering at Wits University. We want to thank Exxaro Resources for providing material for this publication and the School of Mining for their financial support.

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