A cleaner production assessment of the ultra-fine coal waste generated in South Africa

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Synopsis

The South African coal mining industry is currently disposing of about 10 million tons of ultra-fine coal (<150 μm) per year. Once discarded, these sulphur-containing ultra-fines contribute to several environmental problems. As part of a project initiated by the Water Research Commission to investigate the use of Cleaner Production (CP) in the mining industry, a study was carried out to determine whether a CP approach could be used to identify opportunities to reduce this coal waste, and to determine which of these opportunities would be most feasible. In order to do this, a CP assessment was conducted at three case study collieries in the South African Witbank coalfield. Mass-balancing and sampling, followed by laboratory characterisation tests and site surveys, were used to determine the quantity, quality and sources of the ultra-fine coal at the three collieries. Literature reviews, brainstorming sessions and interviews then followed to generate the CP options. An environmental, economic and technical feasibility assessment was then prepared for each option, to determine the most viable interventions for implementation. A number of opportunities were identified through the assessment. By preventing coarser coal from being discarded with the ultra-fine coal, the quantity of coal disposed of could be decreased at all three collieries, and by up to 24% in one case. Increasing the crusher top size would reduce the amount of coal that is milled to less than 150 μm, so that less is wasted. The ultra-fines that have already been disposed of on slurry dams can be completely reclaimed and converted into a valuable product, which can be sold as power station feedstock. The newly processed ultra-fines could be beneficiated using flotation and exported together with the coarser coal. The results of the assessments thus suggested that workable CP opportunities to reduce ultra-fine coal wastage exist at the sites investigated, and that their feasibility is colliery-specific. The associated financial benefits of the proposed options suggested that CP is a realistic approach to addressing environmental problems.

Keywords: Cleaner Production; coal mining; coal-washing; ultra-fines

Introduction

The South African coal mining industry is currently disposing of over 10 million tons of ultra-fine (<150 μm) coal per year,[1] because the industry believes that the high cost of dewatering the ultra-fine coal exceeds its value. However, the quality of this coal is generally equivalent to that of the run-of-mine (ROM) coal, and at some mines the quality is even higher. Once discarded, these sulphur-containing ultra-fines contribute to several environmental problems, including acid mine drainage, dust release and spontaneous combustion. Thus, instead of being viewed as a commodity, coal of good quality is being discarded in large quantities every year, thereby contributing to the environmental damage done by the industry. As part of a project initiated by the WRC to introduce Cleaner Production (CP) in the mining industry, a study was carried out by the University of Cape Town's Department of Chemical Engineering and BECO—the Institute for Sustainable Business—to determine whether a CP approach could be used to find ways to reduce or minimize this coal waste, and to determine which of these are the most feasible. The project was inspired by the successful introduction of CP to several South African industries, most notably metal finishing and textiles[2,3].

Cleaner Production in the context of the mining industry

In the mining industry, where environmental degradation is an unavoidable side-effect, CP is described as a continuous preventative environmental approach with the ultimate goal of reducing wastes at source. There are many other, albeit similar, definitions of CP, but it is outside the scope of this paper to undertake a comprehensive analysis of CP terminology. The actual approach to CP can be applied at physical, managerial and legislative levels[4] via five techniques that are shown in Figure 1.

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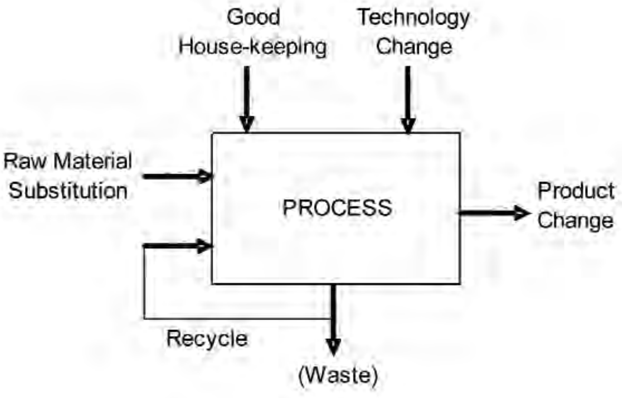

Figure 1—The 5 key CP techniques[6]

Good housekeeping, raw material substitution, technology change, product change and internal recycling are the five generally accepted rules for achieving CP. Product change incorporates resource use optimization[5] and any modifications to the products. Good housekeeping involves improvements in operational procedures and management, such as training and monitoring. Technology changes include improved process automation and substitution, while internal recycling refers to any raw material re-use or recycling that occurs on-site. Since the concept of CP seeks to reduce waste emissions, the costs related to dealing with the waste (i.e. disposal, raw materials, energy, labour, water, transport, clean-up, storage, management time etc.) are also lessened. Thus CP brings about savings as well as lower environmental impacts.

Method

In order to obtain current data about the industry, a CP assessment was conducted at three collieries (referred to as A, B and C) in the Witbank coalfield, South Africa. Table I displays current information pertaining to each colliery.

In the first step of the research, the quantity, quality and sources of the ultra-fine coal had to be established at each of the three collieries. Site surveys and flow sheet analyses were used to determine the sources of wastes. Production statistics formed the basis for developing mass balance calculations, and these were supported by sampling and laboratory characterization of composition, calorific value and particle size distribution.

In the next step, literature reviews, brainstorming sessions and interviews were used to generate CP options. Each was then submitted to a feasibility assessment to determine the interventions that would be most practicable to implement at the collieries. The feasibility assessment procedure is illustrated in Figure 2. As depicted, the options were first subjected to a scan to assess their feasibility, first on technical and environmental grounds, and then on economic criteria. The feasible options that required low capital investments could be implemented, whilst those that required high capital investments were then submitted to an economic assessment. If two mutually exclusive options were both deemed viable, the more profitable would be given preference. Through this process, feasible CP interventions could be identified and recommended throughout the industry.

CP options to minimize the wastage of ultra-fine coal

There are three general methods of reducing ultra-fine coal waste. These are listed below and then discussed:

- ➤ Prevent the unnecessary generation of ultra-fine coal
- ➤ Prevent coarser coal from being discarded with the ultra-fine coal
- ➤ Convert the remaining ultra-fine coal into a useful product.

The last method is considered a CP intervention because, by utilizing the ultra-fines and converting them into a product, waste is being reduced or even eliminated. This type of intervention is known as a 'product change' in terms of the five CP techniques shown in Figure 1.

Prevent the unnecessary generation of ultra-fine coal

Extraction of coal underground is one of the main causes of ultra-fine coal generation. Modern mechanized mining methods result in the production of more ultra-fine coal than manual mining methods. It is, however, highly unlikely that the industry would be willing to revert to manual mining, because of the significant financial benefits of mechanization. Crushing is the other main cause of ultra-fine generation:

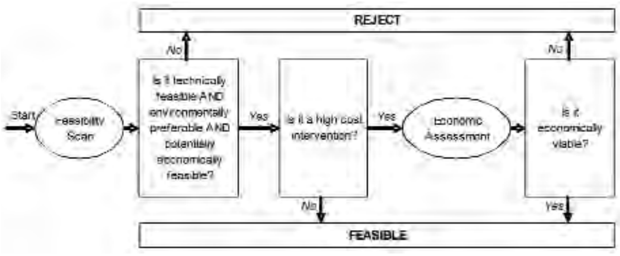

Figure 2—Feasibility assessment procedure

Table I

Relevant case study colliery information

Colliery	Type of mine	Quantity of coal mined (tpa)	Method of ultra-fines disposal	% of Mined coal discarded as ultra-fines	Calorific value: ultra-fines (MJ/kg) air dry
A	Underground	2 900 000	Underground	5 %	22.7
B	Underground	3 900 000	Slurry Dam	4 %	23.7
C	Underground	960 000	Slurry Dam	4 %	22.1

others, such as material handling, are negligible by comparison. Increasing the top, or maximum, size to which the coal is crushed would serve to decrease the amount of ultra-fine and increase the proportion of coarser coal produced. The mined coal is crushed to a top size of 40, 50 and 80 mm at collieries A, B and C respectively. The coarse coal processing equipment is designed to handle coal up to 100 mm in size. Therefore, the crushing top size could be increased while still remaining within the equipment's operating size range. Since colliery C is currently crushing to a large top size, this option is more applicable to collieries A and B. Plant trials should be conducted to ensure that increasing the top size does not compromise the quality of the product.

Prevent coarser coal from being discarded with the ultra-fine coal

Coal that is larger than 150 μm should not be purged with the ultra-fines, as it can easily be upgraded and dewatered at each of the mines. It is therefore unnecessary for +150 μm coal to be discarded with the ultra-fines. Preventing this from happening will reduce the amount of coal that is wasted. Figure 3 displays the particle size distribution of the coal discarded as ultra-fines for the case study collieries (with the 95% confidence limits shown). Based on this information, Table II lists the percentage of coal coarser than 150 μm that is discarded, to within 95% confidence. The information indicates that roughly one-quarter of the coal discarded at colliery A should not have been disposed of in the first place. Although not as significant, there is also a notable wastage at the other mines. The classifying cyclones on the mines are responsible for separating the coal into the coarser and finer than 150 μm size fractions. It can therefore be concluded that the cyclones, particularly at colliery A, are not operating optimally. A CP option is therefore to improve the operation of the classifying cyclones.

Convert the remaining ultra-fine coal into a useful product

Utilizing the ultra-fine waste and converting it into a product is considered a CP intervention because the waste is being reduced or even eliminated. There are several different methods of converting the ultra-fines into a useful product. These are listed and then discussed:

- Beneficiate, dewater and export the ultra-fines
- Dewater and sell the ultra-fines
- Convert the ultra-fines to a low-smoke fuel
- Solubilize the ultra-fines to produce methane and polymers
- Produce a coal-water slurry from the ultra-fines
- Combust the ultra-fines in a fluidized bed combustor

Owing to the ongoing developments of technologies for slurry utilization world-wide, it is likely that several other options are currently available or will become so in the future.

Beneficiate, dewater and export the ultra-fines

This option entails the upgrading of the ultra-fines by beneficiation and the dewatering of the high-quality product. Dewatering is advatageous for several reasons, including reducing transport and port costs and improving the calorific value of the coal and consequently its market value. Flotation is the only effective method of beneficiating ultra-fine coal,[7] and many major coal producing countries, such as Australia, commonly operate flotation plants. In South Africa, the technical feasibility of using flotation to beneficiate the ultra-fines from the Witbank coalfield has been confirmed.[8] In 2000, roughly 12% of the SA coal processing plants utilized flotation to beneficiate the ultra-fines.[9] In terms of dewatering, there are several kinds of equipment suitable for the purpose, including screen-bowl centrifuges, horizontal belt filters and thermal drying. Despite current South African perceptions, a recent study concluded that thermal drying to one percent surface moisture is the most economical method of dewatering the ultra-fines.[10] The combination of flotation

Table II

Volume fraction of the ultra-fine waste that is coarser than 150 μm

Colliery	A	B	C
Volume % coarser than 150 μm	24 ± 3	18 ± 1.3	8 ± 1.4

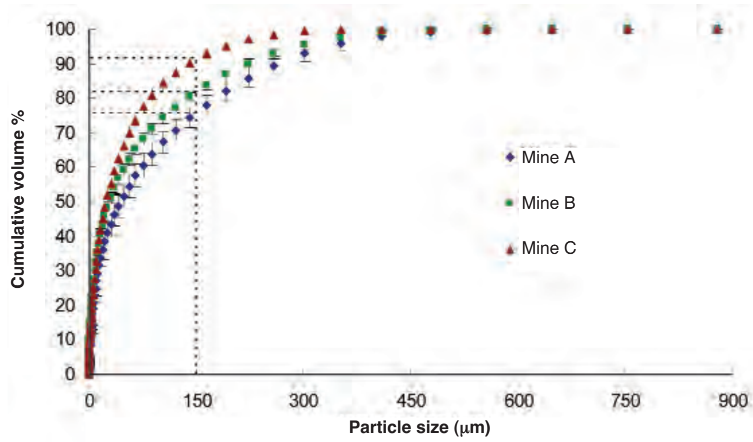

Figure 3—Particle size distribution of the discarded ultra-fine coal

and thermal drying can result in a 75% conversion of the ultra-fines to a valuable product, depending on the quality of the coal. There is no minimum limit on the size fraction of the coal that can be exported by any of the three mines. Therefore the beneficiated and dewatered ultra-fines can be added to the coarse coal, and can be sold to the already established export market. In the case of colliery A, all of the product coal is exported. Only a portion of that produced at the two other collieries is sent abroad.

Dewater and sell the ultra-fines

This option involves dewatering unbeneficiated ultra-fines to sell the result as low-quality coal for electricity generation. Thermal drying of unbeneficiated coal is unlikely to be economically feasible owing to the low value of the coal. Therefore a more cost-effective drying method should be considered. A local BEE private company, Waste Energy Recovery and Management (WERM), has patented a process of drying and recovering ultra-fines from slurry dams using solar energy. Every two to three days the top 300 mm layer of the dam is ploughed and stockpiled. The ultra-fines are dried to between 12–18% moisture because they become difficult to handle outside this range.[11] Once dry, the coal is not easily re-wet if it is stockpiled. This enables the drying process to occur during the rainy season, although a 30–40% decrease in yield is experienced. The dried ultra-fine material is blended with rewashed coarse waste rock and is sold to the Hendrina or Majuba power stations, as other power stations are not equipped to handle the fine material.[11] The purpose of blending the waste rock with the ultra-fines is to lower the overall moisture content. This process converts all of the ultra-fines to a valuable product because WERM operates until the slurry dam is empty. Typically this takes up to five years per mine.[11] This is therefore a short-term option utilizing the coal that has already been discarded in the dams.

Other options to utilize the ultra-fines as they arise from the plant should be considered. The benefits of reducing the problem of acid mine drainage caused by discard dumps, and of producing electricity from coal that does not require to be mined, indicate that this option is environmentally preferable to the current scenario. However, an in-depth investigation should be conducted to establish the environmental impacts caused by burning ultra-fines and rewashed waste rock to generate electricity. This option does not apply to colliery A, as this mine currently disposes of its ultra-fines underground rather than in dams.

Convert the ultra-fines to a low-smoke fuel

This CP option entails converting the ultra-fine coal to a low smoke fuel (LSF). These are fuels that release low levels of smoke emission when burnt. They are widely used in many countries, including the United Kingdom, Poland and India. LSF could provide a solution to the vast amount of air pollution brought about by the burning of coal for domestic usage, particularly in informal settlements. In order to convert ultra-fine coal into a low smoke fuel, the coal should first be agglomerated to make it more easy to handle. Various methods of agglomeration are available, including pelletizing, extrusion, binder and binderless briquetting. The latter was found to be the most economically viable[12]. To convert the coal into a low-smoke fuel, the briquettes are devolatised at high temperatures.

Pilot and laboratory tests have been conducted at Kleinkopje Colliery by Coaltech 2020 to establish the technical feasibility of the production of low-smoke fuels from ultra-fines in South Africa. The tests confirmed that the process is technically feasible with South African coal.[13] A study by England[12] concluded that the costs of briquetting are much higher than the price of D-grade coal. Therefore it is unlikely that low-smoke fuels will be adopted by the domestic sector unless subsidized or mandated by law. Therefore, this option is not likely to be economically feasible at present.

Solubilize the ultra-fines to produce methane and polymers

Coal solubilization is the process through which coal is converted by micro-organisms and enzymes into a solution of coal macromolecules. These in turn can be converted into various products, such as methane or polymers.[14] Low-rank coals, such as lignite, are more susceptible to solubilization because of their higher moisture content, more suitable structure, smaller pores, softness and susceptibility to weathering.[15] However, certain micro-organisms can solubilize higher-rank coal.[16] The lack of standardization of research work in this field is hindering the progress and development of the process. In South Africa this technology is not commercially available at present, although research work is being undertaken at local universities to optimize and commercialize this process.

Produce a coal-water slurry from the ultra-fines

Coal-water slurries (CWS), also known as coal-water fuels (CWF) or coal-water mixtures (CWM), are concentrated suspensions of highly beneficiated ultra-fine coal in water. The CWS must be between 65–70% solids and three to four % ash. The CWS can be produced from the ultra-fine slurry by undergoing extensive crushing and grinding to improve liberation of the high-grade coal so that the low ash requirements can be met.[7] The CWS is piped directly to power stations where it is burned as a heavy oil, rather than being added to the coarse coal. Coal-water slurries have several advantages over traditional dry coal. The problems of spontaneous combustion and dust generation during storage and transportation of dry coal are eliminated. The cost of drying and dewatering are significantly reduced, and coal-water slurries are more easily handled because, being aqueous, they require no large-scale transportation or handling facilities.[7] However, there are currently no power stations in South Africa that can utilize coal-water slurries because they are limited to handling dry coal. Therefore, until there is a use for the CWS, this option is not economically feasible.

Combust the ultra-fines in a fluidised bed combustor

A fluidized bed reactor is a combustor in which the coal particles are suspended in a bed by updrafts of gas that keep the coal in a turbulent state.[17] Research by the CSIR[18] has

Table III

Feasibility Scan

Option no.	1	2	3	4	5	6	7	8
Technical Feasibility								
Is it proven technology?	✓	✓	✓	✓	✓	✘	✓	✓
Can the technology be implemented in SA at present?	✓	✓	✓	✓	✓	N/A	✘	✘
Environmental Feasibility								
Is it likely to result in a net reduction of environmental impacts?	✓	✓	✓	✓	✓	?	✓	✓
Is there a reduction in wastage of coal?	✓	✓	✓	✓	✓	✓	✓	✓
Economic Feasibility								
Is it potentially financially feasible at present?	✓	✓	✓	✓	✘	✘	✘	✘

established that it is technically feasible to combust ultra-fine coal slurries of 63% moisture in a fluidized bed combustion boiler. Conventional pulverized fuel boilers require that the feed coal contains at most ten percent moisture. Therefore the cost of dewatering the ultra-fine coal is greatly reduced for the fluidized bed reactor. Although a relatively low thermal efficiency of 67% is achieved, the costs of obtaining this waste coal are also low. Transport other than via pipelines is not feasible, as the slurry is not sufficiently stable.[18] There are currently no commercial fluidized bed combustion power stations in South Africa that run on coal, although Eskom plans to install and operate them in the unspecified future. Therefore this option is not currently economically feasible, but it may become so over time.

Feasibility of the CP options

The various CP options that have been suggested for the ultra-fines are summarized below:

- Increase the crusher top size
- Optimize the performance of the classifying cyclones
- Beneficiate using flotation, + thermal drying, and export the ultra-fines
- Dewater the unwashed ultra-fines and supply to local power stations
- Convert the ultra-fines to a low-smoke fuel
- Solubilize the ultra-fines to produce methane or polymers
- Convert the ultra-fines into a Coal-Water Slurry (CWS)
- Combust the ultra-fines in a fluidized bed combustor

Due to better performances at colliery C, options 1 and 2 are more applicable to collieries A and B. As described in the Method section, each option was subjected to a feasibility assessment, commencing with the feasibility scan to discard any options that do not meet certain criteria. The criteria are shown in the left-hand column of Table III. Negative answers (✘) signify that the option is unsuitable, and will not be considered any further. The option numbers in Table III correspond with the option numbers listed above. The information provided in the previous section was used to complete this scan. The results of the scan were the same for all three mines, with the exception that option 4 cannot be implemented at colliery A as ultra-fines are disposed of underground.

Table III indicates that options 5–8 will no longer be considered for implementation, as they are not currently viable. However, they should not be completely dismissed because they may become workable in the future. The remaining options (1–4) are all considered technically feasible and environmentally preferable (with some uncertainties remaining over option 4), as they have satisfied the criteria in the left-hand column of Table III. Owing to the fact that options 1 and 2 require no or low capital investments, these options did not require an economic feasibility study, as per the procedure outlined in the Method section. Since these options are not mutually exclusive, they can be implemented immediately. Options 3 and 4 are both high-cost options, and were therefore submitted to a generalized economic feasibility assessment. The results for option 3, flotation and thermal drying of the ultra-fines, are summarized in Table IV, and the assumptions are listed in Table V. Operating and capital costs were based on those used by de Korte[7]. The net present values (NPV) indicated in Table IV reflect the difference between the current profits and those that would result if option 3 was implemented. The values indicate that an increase in NPV of at least R50 million could be achieved over a ten-year period by implementing option 3 at any of the mines. This information indicates that option 3 is financially, as well as environmentally, strongly beneficial. With regard to option 4 (contracting an independent operator to solar-dry the ultra-fines) the results

Table IV

Net Present Value (NPV) and capital investments for option 3

Colliery	A	B	C
NPV (10 years)	R 100,000,000	R 200,000,000	R 50,000,000
Capital	R 10,000,000	R 10,000,000	R 6,000,000

Table V

Option 3 Assumptions

Flotation yield[5]	75 %
Flotation product air-dry CV[5]	28 MJ/kg
Revenue from coal export sales†	A: R278/t; B: R279/t; C: R297/t
Cost of railage, truckage and port fees†	A: R 58/t; B: R 59/t; C: R 81/t
Discount rate	15%

† Average values for 2005 for the respective collieries

Table VI

Net Present Value (NPV) for option 4

Colliery	B	C
NPV	R 50,000,000	R 15,000,000
Period of Contract	5 years	2 years

Table V

Option 4 Assumptions

Product produced per month	Mine B: 100 000 t*; Mine C: 60 000 t*
Revenue from coal sales	R 60 / product ton*
Contracting cost	R 42.5 / product ton*
Cost of discards disposal	R 2 / ton of discards[5]
Yield of the rewashed waste rock	50 %*
Tax	29 %
Discount Rate	15 %

* Based on an unofficial rough quote from WERM

of the economic assessment are summarized in Table VI, and the assumptions listed in Table VII. Colliery A has not been included in the assessment as this option is not suitable for this mine. Table VI indicates that option 4 is economically strongly viable at both of the other collieries. However, the feasibility of option 4 ultimately depends on whether or not the collieries are able to establish a contract agreement with Eskom. While further, more intensive feasibility assessments should be conducted before options 3 and 4 are implemented, it is clear that CP could reduce the dumping of the ultra-fines at the collieries significantly.

Conclusions

CP assessments have been prepared for three collieries in the Witbank coalfield, that were thought to be sufficiently typical of practices in the South African coal mining industry for the results to have general significance. The assessments found that there are technically and economically feasible options for reducing the environmental hazards brought about by the common practice of dumping ultra-fine coal in South Africa. The findings indicated that the generation of this waste or of coarser coal contained in it could be reduced, at low cost, by optimizing crusher and cyclone performance. The remaining ultra-fine coal waste can be economically upgraded or recovered and sold, either into the export market or locally, with attractive returns on investment. However, the feasibility of each option, as the case study assessments have indicated, depends on the colliery. The associated financial benefits of the proposed options suggested that CP offers a realistic approach to addressing environmental problems.

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