Characterization of inorganic material in Secunda coal and the effect of washing on coal properties

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Synopsis

The objectives of this study were firstly to characterize and quantify the inorganic material in the Secunda gasification feedstock. Secondly, the effect of washing on coal properties and sulphur content was investigated. Coal from a single source and a coal blend from 6 different mines were tested. Composite samples were visually sorted by a geologist in the groups containing roof, floor, C-shale, pyrite, carbonates and siltstone material. Inorganic mineral types from the single source and coal blends were characterized separately. Characterization results indicate that the average mineral matter distribution (mass %) of the coal tested was as follows: carbonates (6%), carbon-shale (19%), pyrite (12%), roof (18%), floor (46%) and siltstone (22%). The roof, floor, pyrite, carbon-shale, carbonates and siltstone in the single source and coal blend have similar chemical properties and characteristics, except for the ash melting temperatures of pyrite and kaolinite in the siltstone.

By implementing selective mining and increasing mining management practices, the percentage discard in the run of mine coal can be significantly reduced, by up to 45%, if the mining of roof and floor material can be avoided. No significant impact of mining practices on sulphur content is expected in this case due to the low concentrations of sulphur in the roof and floor material. In summary, selective mining practices will probably result in almost 45% decrease in the discard content in the run of mine to gasification, an increase in the carbon content from 55.0% to 58% (air dry basis) and a decrease in sulphur content from 1.1% to 0.9% (air dry basis). It is clear from this study that the main source of sulphur is not in the high ash-content mineral types (e.g. floor and roof), but *in situ* in the coal structure.

Keywords: inorganic material, effect of washing, roof, floor, pyrite, C-shale, carbonates and siltstone

Introduction

Two years ago Sasol embarked upon a unique project to optimize the performance of the Sasol-Lurgi Fixed Bed Dry Bottom gasification process. The overall objective of the test gasifier project is efficiency improvement. The parameters investigated in the first phase of the project were stone content (defined as the discard material that sinks at a relative density of 1.95), coal particle top size, coal particle bottom size, gasifier load, CO_2 in raw gas levels, and the effects of these parameters on pure gas yield, oxygen and steam consumption and product carbon distribution.

In order to minimize the effect of feedstock variability on gasifier performance, the first test series was conducted with coal from a single source. Since the normal day-to-day plant feedstock consists of a blend from 6 different mines, it was questioned if the test results obtained with the single source are representative of the normal operation with the blend. This study focuses on the characterization and the differences and similarities of the single source and blended feedstock with regards to the discard material (i.e. mineral portion).

Coal from a single source and a blend from 6 different mines were prepared by beneficiation at a relative density of 1.95. Stone content in this context refers to all material with a relative density >1.95. The stone was prepared to the same particle size as the coal, so that back blending would not affect the particle size distribution (PSD) aimed for. Tests with destoned coal, as well as coal with 10% and 5% back blended stone, were conducted. During some of the test runs additional samples of the discard product were taken for analyses and characterization.

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Sampling and preparation of discard

Comprehensive reports and papers have been compiled on the preparation of the coal and performance of the test gasifier at Sasol Synfuels in Secunda[1]. This paper will not deal

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with that part of the work and will only focus on the characterization and properties of the discard material from the coal that was used during those tests. For background information and understanding of terminology throughout this paper, stone content or discard material is defined as material with a relative density >1.95.

During the coal blend preparation representative samples of the discard product (RD > 1.95) were taken from the discard stockpile. All discard samples of each test were then grouped together and homogenized as one composite sample. The discard batch from the single coal source as well as the blend were visually inspected by a geologist from Sasol Mining and divided into the following groups: roof, floor, pyrite, carbon-shale (C-shale), carbonates and siltstone.

The following analyses were done on each sample: proximate analysis, ultimate analysis, ash composition, ash melting temperatures (oxidizing to 1600°C) and XRD.

Results

Characterization of discard material (RD > 1.95)

Comparison of mineral matter yields in discard (single source and blend)

Discard samples of the single coal source might differ from that of the coal blend which contained discard product from 6 different mines.

It has to be taken into account that the outcome of this study might be different when a different geologist was used during this study and that the results are in a way subjective. However, the following conclusions can be drawn on the mineral type distribution in the discard of the single coal source in comparison with the coal blend:

- Carbonates in the single coal source and coal blend vary between 3% and 13%. The average carbonate content in the single coal source and coal blend is in the order of 6.5%
- The average C-shale content of the single coal source and coal blend is 18%
- The average pyrite content of the single coal source and coal blend are, respectively, 14% and 10%, with one sample of the single coal source which contained an extremely high pyrite content of 32%
- Discard from the single coal source and coal blend showed a definite step change in the roof content, with an average of 10% in the single coal source and 24% in the coal blend. Discard from the coal blend was a composite sample from 6 different mines and thus mining procedures or underground operations from one or more other mines could have contributed to this finding
- The single coal source showed a decrease in floor content from 32% to 6%, with an average of 24% over the test period. The average floor content in the discard of the coal blend is 20%. This decreasing trend in floor content of the single coal source is inversely related to the siltstone content
- The siltstone content of the single coal source increased from 16% to 55%. Discard of the single coal source had an average siltstone content of 25% and the coal blend discard 20% siltstone.

The roof content was the only mineral, according to XRD analyses, that showed a significant difference between the single coal source and coal blend. All the other minerals (i.e. floor, carbonates, C-shale, pyrite and siltstone) showed little or no differences between the average mineral content in the single coal source and coal blend, although variation was seen within the test period. This confirms that the single source and blended feedstock are very similar with regards to their discard portion.

Interesting to note was that the floor content decreased over the test period and that the siltstone content increased during the same period. Floor and siltstone both have the characteristic of high SiO_2 and Al_2O_3 contents or high quartz and kaolonite contents, and the inverse effect (decrease in floor and increase in siltstone) will possibly result in a net zero effect.

Comparison of mineral matter composition in discard (single source and blend)

As already indicated, the samples were visually divided into the 6 mineral groups. It is thus necessary to compare the discard properties and chemical characteristics of the single coal source with that of the coal blend in order to determine if any qualitative differences exist. The generalized terms, e.g. 'pyrite' or 'siltstone' were compared for the single source and the blend.

The mineral matter of the single coal source and coal blend were compared according to the 6 different groups: carbonates, C-shale, pyrite, roof, floor and siltstone. Average values of each mineral group were determined for the single source and the blend.

Carbonates

Carbonates in both the single coal source and coal blend have the following characteristics:

- Volatile matter is approximately 26%
- The C-content in the single coal source and coal blend is, respectively, 25% and 23%, with a high S content of 16% and 17% (air dry basis)
- Both the single coal source and coal blend have a high SiO_2, Fe_2O_3 and CaO content
- The high pyrite content is confirmed by the high Fe_2O_3 and S content
- The ash melting temperatures are in the order of 1250°C. These low ash melting temperatures are likely to be caused by the high CaO and Fe_2O_3 content.

Table I

Average mineral matter yields in the discard (mass %)

Mineral type	Single coal source	Coal blend
Carbonates	6	6
C-Shale	19	18
Pyrite	15	10
Roof	10	25
Floor	25	21
Siltstone	25	20

C-shale

C-shale in the single coal and coal blend can be described as follows:

- Volatile matter is in the order of 13%
- The C-content in the single coal source and coal blend is, respectively, 24% and 15%, with an S content of 1.8% and 1.2% (air dry basis)
- Ash melting temperatures are in excess of 1500°C
- C-shale of both the single coal source and coal blend have high SiO_2 and Al_2O_3 contents
- XRD analyses indicated that the quartz and kaolonite content of C-shale are high.

Pyrite

The following characteristics of pyrite are visible in the single coal source and coal blend:

- Volatile matter is in the order of 23% to 26%.
- The C-content in the single coal source and coal blend is, respectively, 25% and 22%, with a high S content of 17% and 12% (air dry basis)
- Both the single coal source and coal blend have high SiO_2, Fe_2O_3 and CaO contents
- The high pyrite content is confirmed by the high Fe_2O_3 and S content
- The ash melting temperatures of the single coal source and coal blend differ by approximately 150°C. Pyrite in the single coal source has an ash melting temperature in the order of 1450°C and that of the coal blend approximately 1300°C. Although the CaO and Fe_2O_3 content of both the single coal source and coal blend are high, the ash melting temperature of the single coal source pyrite is not as low as expected
- As the name pyrite indicates, XRD-analyses showed a high pyrite content of >60%.

Roof

Mineral matter identified as roof in the single coal source and coal blend has the following characteristics:

- Low volatile matter content in the order of 6%
- The C-content in the single coal source and coal blend is <3% and the S content <1.8% (air dry basis)
- Both the single coal source and coal blend have a high SiO_2 content of >80%
- XRD analyses showed high quartz (>50%) and kaolonite (±20%) contents
- The ash melting temperatures are in the order of 1550–1600°C.

Floor

Floor in the single coal source and coal blend can be described as follows:

- Low volatile matter content in the order of 7–8%
- The C content of the floor is <5% and the S content in the order of 1% (air dry basis)
- Both the single coal source and coal blend have a high SiO_2 content ±(70%) and Al_2O_3 content (±20%)
- XRD-analyses showed high quartz, illite and microline contents
- The ash melting temperatures are in the order of 1550–1600°C.

Siltstone

Siltstone in the single coal source and coal blend has the following characteristics:

- Volatile matter content in the order of 11%
- The C-content in the single coal source and coal blend is, respectively, 18% and 15% with the S content in the order of 1.5% (air dry basis)
- Both the single coal source and coal blend have a high SiO_2 content ±(70%) and Al_2O_3 content (±20%)
- XRD analyses showed high quartz and kaolonite contents, with the kaolonite content in the coal blend (35%) almost double the kaolonite content in the single coal source (18%)
- The ash melting temperatures are in the order of 1500–1550°C.

According to the above results, it can be concluded without any doubt that the mineral matter (roof, floor, pyrite, C-shale, carbonates and siltstone) in the single coal source and the coal blend have very similar characteristics and gasifier operation with the two different feedstocks can thus be expected to be very similar.

Comparison of roof, floor, pyrite, C-shale, carbonates and siltstone characteristics

As concluded earlier, the different mineral matter types in the single coal source and coal blend have approximately the same characteristics, and it was decided to use an average value for each discard type which describes the characteristic of the specific mineral type for the single coal source and the coal blend.

Proximate analyses

The percentage moisture, ash, volatile matter and fixed carbon was determined on each individual sample and the average calculated for each mineral type (Figure 1).

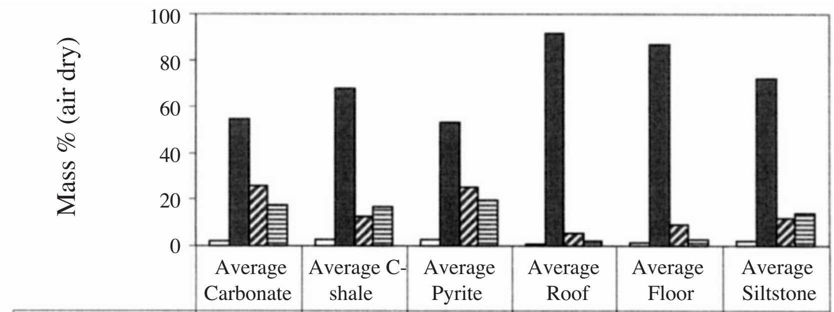
Roof, floor and siltstone have an ash content >70%. The low fixed C and volatile content in these mineral types are thus zero or close to zero value for the gasification process. Roof, floor and siltstone probably have a relative density >1.95 and it is highly likely that this material will be removed by destoning the run of mine coal.

The ash content of the carbonates, C-shale and pyrite is also high (50–70%), but the fixed C is in the order of 18% that might contribute to the production of syngas. Carbonates and pyrite also have a high volatile content (25%) that will add value to the production of liquid hydrocarbons. Value-adding of carbonates and pyrites to gasification might be positive with respect to C, but the negative influence of other factors, e.g. sulphur, will be discussed below.

C- and S-content

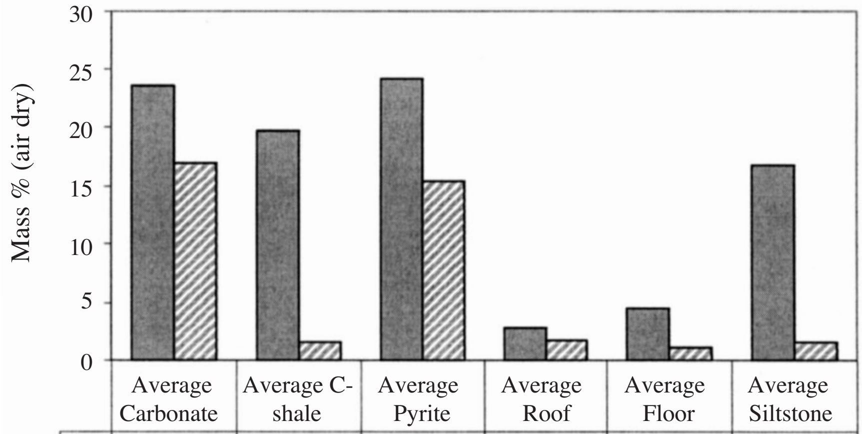
An ultimate analysis (C, H, N, S) was done on each individual discard sample. The average C and S content of all samples for the different mineral types is given in Figure 2.

The average C content of the mineral types, as given in Figure 2, again indicated that the discard type roof, floor and siltstone are the high ash content types with a low total C content. The value of roof, floor and siltstone with respect to syngas production is minimal. Carbonates, C-shale and pyrite have a slightly higher total C content (16–24%) and might positively contribute towards the production of syngas.



	Average Carbonate	Average C-shale	Average Pyrite	Average Roof	Average Floor	Average Siltstone
% Moisture	2.4	2.6	2.5	0.8	1.2	2.3
% Ash	54.2	67.8	53.0	91.4	86.6	71.7
% Volatile matter	26.0	12.9	25.0	5.9	9.1	11.8
% Fixed Carbon	17.4	16.7	19.6	1.9	3.1	14.2

Figure 1—Average proximate analyses for discard types



	Average Carbonate	Average C-shale	Average Pyrite	Average Roof	Average Floor	Average Siltstone
C	23.6	19.7	24.1	2.7	4.5	16.8
S	17.0	1.5	15.4	1.7	1.1	1.6

Figure 2—Average carbon and suphur content

S content of a feedstock is important for environmental reasons to reduce S emissions from gasification. C-shale, roof, floor and siltstone have a low S content (<1.5% on an air dried basis), but they are also the high ash content mineral types. Carbonates and pyrite, which have a higher C-content, also have an extremely high S content (>15% air dry basis). The contributing value of the total C content must be compared with the S emissions and the negative effect on the environment. The high S content discard types (carbonates and pyrite) are the mineral types where the contamination is probably *in situ* in the coal structure and difficult to remove by destoning without further liberation by crushing.

In another study[1] it was also found that maximum 30% of the S could be removed by destoning up to a relative density of 1.85. Again it confirms the findings that S is mostly *in situ* in the coal and the removal of S is limited.

Ash composition

Ash composition analysis was done on each sample and the average SiO_2, SO_3, CaO and Fe_2O_3 given in Figure 3.

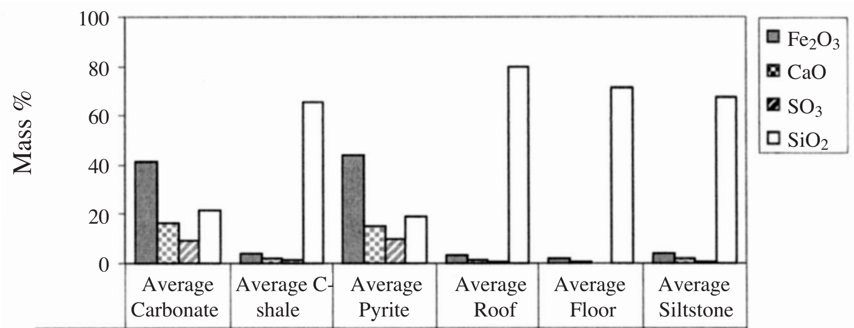
C-shale, roof, floor and siltstone, which all have a high ash content, showed an SiO_2 content higher than 60%. Carbonates and pyrite both have high S contents with high percentages of Fe_2O_3, SO_3 and CaO. The high S content of these two discard types can be explained by the high SO_3 and Fe content (pyrite). It is also known that high Fe_2O_3 and CaO content products have mostly low ash melting temperatures.

Ash melting temperatures

The average ash melting temperatures are shown in Figure 4. As already indicated, the ash melting temperatures of carbonates and pyrite are lower than these of C-shale, roof, floor and siltstone. These low ash melting temperatures (1250–1350°C) were a possible result of the higher Fe_2O_3 and CaO content in the discard. All other discard types have an ash melting temperature >1500°C.

XRD analyses

XRD analyses give the phases of the different mineral types present in a sample. Average kaolonite, calcite and pyrite contents of the discard samples are given in Figure 5.



	Average Carbonate	Average C-shale	Average Pyrite	Average Roof	Average Floor	Average Siltstone
Fe_2O_3	41.1	3.8	43.7	3.6	1.9	3.6
CaO	16.3	2.0	15.1	1.2	0.4	1.8
SO_3	9.4	1.6	10.1	0.7	0.1	0.9
SiO_2	21.8	65.3	18.8	80.1	71.5	67.0

Figure 3—Average ash composition

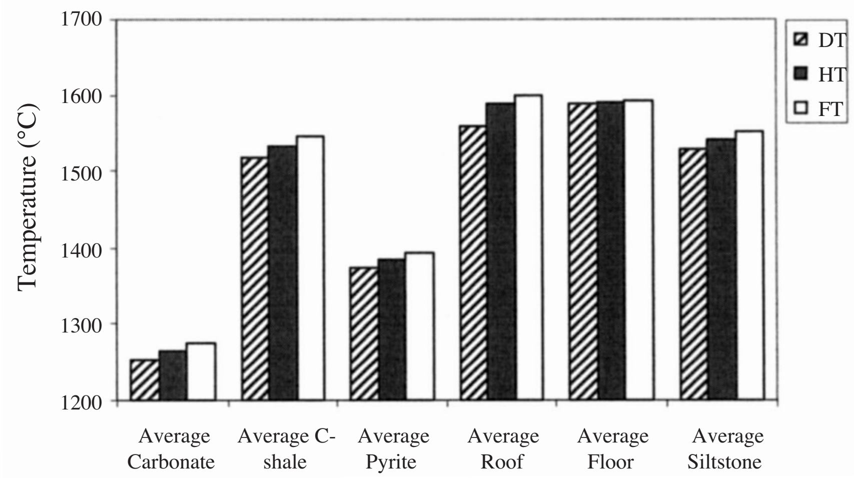
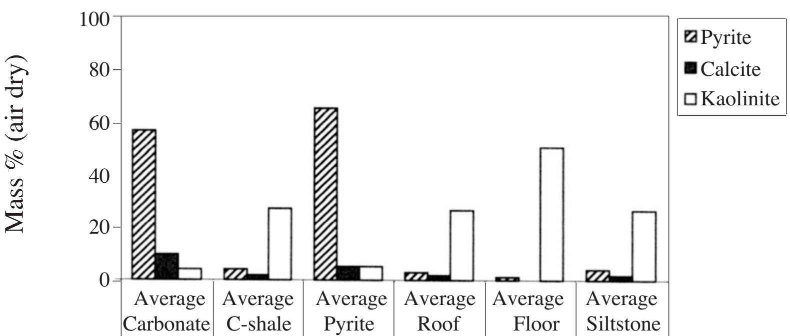


Figure 4—Average ash melting temperatures (°C)



	Average Carbonate	Average C-shale	Average Pyrite	Average Roof	Average Floor	Average Siltstone
Pyrite	56.8	4.2	65.6	2.7	1.4	4.2
Calcite	9.9	1.8	4.9	1.5	0.1	1.7
Kaolinite	4.3	27.4	4.9	26.5	50.8	26.8

Legend:

Calcite	($CaCO_3$)
Pyrite	(FeS_2)
Kaolinite	($Al_2Si_2O_5(OH)_4$)

Figure 5—Average XRD-analyses of discard samples

XRD-analyses are just another confirmation test of the results discussed earlier.

- Carbonates and pyrite groups have a high FeS_2 (pyrite) content
- Carbonates and pyrite also have the highest calcite ($CaCO_3$) content
- Discard types (C-shale, roof, floor and siltstone) with the highest ash content contain the most kaolonite.

Effect of selective mining procedures on coal properties and sulphur content

It is indicated by theoretical predictions and experimental data that destoning at a relative density of 1.95 decreases the sulphur content of the coal feed by ±30%[1]. From the available data and detail coal characteristics it can be summarized that washing of a typical Sasol ROM coal feed at a relative density of 1.95 has the following effect on coal properties:

- Percentage C increased by 5–8% per ton product. However, approximately 1.5% C per ton ROM coal is situated in the discard that will be lost
- S content per ton product will decrease from 1.1% in the ROM coal to 0.78% (air dry basis) in the destoned product. This also implies a decrease of ±30% in S content.

Two of the contaminants, namely roof and floor, are probably manageable by more selective mining. This implies that the roof and floor content can be decreased without the expensive operation of destoning. Discard from the coal blend contains, respectively, 25% and 21% roof and floor. These two mineral types contribute 46% to the total discard. It is thus 4.9% of the 10.7% discard in the ROM coal that can be removed by more selective mining.

More selective mining, implying very optimistically that no roof and floor will be included in the current ROM coal, will have the following impact on coal quality:

- Total discard can decrease by 45% (from a 10.7% discard to a 5.8% in the ROM to gasification)
- C content per ton product will increase from 55.0% to 57.7% (air dry basis)
- S content per ton product will decrease from 1.1% to 0.9% only. Again it is clear and highlighted in this study that the main source of sulphur is not in the high ash content mineral types (e.g. floor and roof), but *in situ* in the coal structure.

Conclusions and recommendations

Characterization results indicate that the average mineral matter distribution (mass %) of the coal discard tested was as follows: carbonates (6%), C-shale (19%), pyrite (12%), roof (18%), floor (46%) and siltstone (22%). The roof, floor, pyrite, C-shale, carbonates and siltstone in the single source and coal blend have similar chemical properties and characteristics, except for the ash melting temperatures of pyrite and kaolinite in the siltstone.

By implementing more selective mining practices, the percentage discard in the ROM coal can be significantly reduced, by up to 45%, if the mining of roof and floor material can be avoided. No significant impact of mining practices on sulphur content is expected in this case due to the low concentrations of sulphur in the roof and floor material. In summary, more selective mining practices will probably result in an almost 45% decrease in the discard content in the ROM to gasification, an increase in the carbon content from 55.0% to 58% (air dry basis) and a decrease in sulphur content from 1.1% to 0.9% (air dry basis). Again it is clear and highlighted that the main source of sulphur is not in the high ash content mineral types (e.g. floor and roof), but *in situ* in the coal structure.

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