

## CHAPTER ELEVEN - CONCLUSIONS

The objective of this research was to use a model of a beneficiation plant to which was added a liberation function model, low grade export quality model, a coal pricing model and an emission reduction model in order to produce an optimal combination of energy produced with minimal emissions and maximum triple bottom line benefit.

Towards this end research was conducted from which the following conclusions may now be drawn:

### 11.1 Method to characterise coal quality and liberation

1. The application of coal characterization techniques like QEMSEM, XRD and petrography discussed in the thesis have shown that coal and mineral particles from ROM, size fractions (PSDs) and various washability test density fractions differ significantly in their composition and, therefore, in their behaviour during beneficiation and subsequent utilisation. These advanced techniques have provided a better understanding into the characterisation of coal particles on a micro-level and the potential to predict behaviour during beneficiation and utilisation.
2. Through the identification of maceral content by petrographic analysis, a correlation was established between maceral content (by volume) and certain conventional rank parameters of the coal such as the calorific value and volatile content. Namely, the vitrinite and reactive inertinite content parallels the calorific value and the volatile content in both the Witbank Coalfield No. 4 Seam and Waterberg Upper Ecca coals.
3. A correlation was also established between QEMSEM, forms of sulphur and petrographic analytical results thereby providing a quantification of broad maceral content *by mass* and not just by volume as is the case with normal petrographic analyses. This has provided a more realistic distribution of

maceral components by mass which provides data for quality prediction and weighted liberation models.

4. The microlithotypes provided a good indication of the maceral and mineral proportions and their associations. The microlithotype data have proved to be useful in the prediction of beneficiation effectiveness and associated product qualities for subsequent utilisation. The above identification is pivotal in the identification of the optimal beneficiation strategy and minimisation of process losses in the form of product misplacement.

## 11.2 Beneficiation models and liberation indices

5. Advanced liberation models were adapted and populated with mineralogical and petrographic data in order to derive trends for the beneficiation potential of specific mineral and organic matter. From the petrographic data for both macerals and microlithotypes an advanced equation (Equation 12) for modelling of organic matter was derived. Through the adjustment of the equation parameters, this equation can be used to predict the liberation and therefore beneficiation potential of macerals and microlithotypes for different coals.
6. The Witbank Coalfield No. 4 Seam and the Waterberg Upper Eccra coals were found to have distinct liberation patterns and indices for minerals and macerals. This illustrated that a specialised beneficiation approach was required for each coalfield in order to derive optimal value. The higher quality Witbank Coalfield No. 4 Seam coal was found to possess a lower carbominerite concentration than the lower quality Waterberg Upper Eccra. The mineral liberation data indicated that the Witbank Coalfield No. 4 Seam has a high concentration of fine pyrite nodules and cleats in the low density maceral matrices which, from a practical washability perspective, indicate that mineral reduction can only occur to a limited extent. This coal, however, has a higher liberation potential for the clays and quartz minerals which reported to the high density fractions thereby producing a higher proportion

of cleaner low density product for utilisation purposes. In contrast, the Waterberg Upper Ecca displayed a higher liberation index for the pyrite (which reported to the high density fractions) and, with its limited liberation of clays and quartz, provided lower proportions of saleable utilisation products.

7. Coal beneficiation models were populated with data from recently developed coal processing technologies including the XRT sorting process, the Three-Product Cyclone and the FGX separation method. The models were utilised to assess the beneficiation potential of the Witbank Coalfield No. 4 Seam, Waterberg Upper Ecca and Free State (Vereeniging) coals to produce low to high grade export and domestic saleable coal. Results for all processes confirmed the results as shown in the liberation model in point 6 and the liberation indices provided a comparison for the percentage near gravity material in each of the coals. Namely, they all indicated the different beneficiation potentials between the Witbank and Waterberg coals with the Witbank No 4 Seam coal proving to have the lower percentage near gravity material and therefore better washability potential.

### **11.3 Applied beneficiation modelling to predict pollutant reduction**

8. From the analysis of raw ROM samples from the Witbank Coalfield No. 4 Seam, Waterberg Upper Ecca and Free State coals, the concentration of trace elements of major concern that have a higher concentration than the global average was identified. These trace elements include mercury, arsenic and molybdenum, whilst those that occur in proportions lower than the global average include selenium, cadmium and lead.
9. From the analyses of the different washed fractions in this research programme, it was established that the concentrations of most trace elements in the final marketable coal product can be controlled to some extent by beneficiation processes. Namely, traditional dense medium processes could be used to reduce mineral content and thereby the specific

trace elements associated with those minerals. However, it has been established that a low density product with low ash and high volatile content, does not necessarily guarantee a product with a low concentration of some detrimental trace elements (for example mercury and arsenic). This is because such trace elements in many instances concentrate in fine mineral matter in the low density macerals in that density range.

10. The Principal Component Analysis (PCA) and correlation analysis indicated that there are distinct relationships between sulphur, HAPs trace elements and their host minerals and macerals. In the case of the Waterberg Upper Ecca and Witbank Coalfield No. 4 Seam, correlation factors of 0.97 and 0.99 respectively were found for the relationship between the mineral pyrite and trace element arsenic. The Principal Component Analysis indicated similar statistical associations of arsenic and sulphur in vitrinite. Due to the distribution of pyrite, froth flotation could be considered as a process to obtain pyrite reduction in the case of the Waterberg Upper Ecca.

11. The impact of these observations is that a decrease in product quality in terms of increased percentage ash does not necessarily result in increased HAPs emissions such as mercury, arsenic, cadmium and fluorine. This is due to the identification of correlation factors between some trace elements and macerals. Some trace elements were identified to have close relationships with organic compounds, for example organically bound As and Hg in some macerals which reported in the lower densities.

#### **11.4 Techno-economic & environmental impact modelling**

A number of existing economic and novel environmental impact models were adapted in this thesis. From these, the following observations and conclusions can be drawn:

12. For the Witbank Coalfield No. 4 Seam, it was identified that wet dense medium processing with dense medium cyclones and baths provided the optimum economic benefit when producing a traditional 6000 NAR CV

primary export product and 28.0 percent ash middling product with a NAR CV of 4800 kcal/kg for domestic power generation.

13. The optimal combination of economic and environmental factors for processing the Witbank Coalfield No. 4 Seam was found to occur by producing a 5400 NAR CV product through dry screening and coarse size fraction beneficiation with DSM Cyclones. Co-incidentally this set of circumstances also provided the local minimum sulphur content as indicated by the sulphur washability curve.
14. The Three Product cyclone modelling indicated a benefit in producing a primary and secondary low grade export product. In the correct market conditions, a high and low grade thermal export product could be deemed viable, but again would only be applicable to a 'higher' quality coal reserve. It was found that the total yield obtained from a Three Product Cyclone was lower than the total yield obtainable with a double stage primary and secondary processing circuit. The separated double stage circuit allows for a liberation step prior to processing the secondary product.
15. It was found in the case of the Witbank Coalfield No. 4 Seam that for dry coal processing to be viable, a high process density cut-point is required, namely, above 1.80 RD. Operating at densities below 1.80 RD resulted in uneconomically high process losses through misplacement. It was also found that, in combination with dry screening, the raw medium to fine size fractions added to the unwashed product resulted in higher SO<sub>x</sub> and CO<sub>2</sub> emissions per unit energy
16. The highest value-adding beneficiation option identified from the Waterberg Upper Ecca modelling was the dry screening and de-stoning combination option. This was modelled simulating the production of a 4000 NAR CV (18.63 MJ/kg air dried basis) domestic thermal product.

17. Gas Cleaning (Wet FGD, ESP) costs and power increases were evaluated for each processing option and it was found that high quality, low ash products would not necessarily result in low gas cleaning costs. This is due mainly to the complex distribution of sulphur in the coals. It has also been shown that higher energy recovery would offset the increase in pollutants, as more power can potentially be generated for the volume of emissions emitted, especially in the case of the Witbank Coalfield no. 4 Seam.

In summary, this research has sought to produce an optimum combination of energy produced with minimal emissions and maximum triple bottom line benefit in the course of the beneficiation of the three South African coals. In so doing, modelling has highlighted a number of important aspects, all of which bear strong relation to the future use and marketing potential of South Africa's remaining coal reserves. Coal has been identified as a potential strategic mineral in South Africa. The balance between maintaining GDP growth and energy security is of utmost importance. The research illustrated the benefit of the production of a range of low grade export products from low potential reserves versus producing the traditional high grade export. The research also showed that in some instances production for the local power utilities indeed generates optimum value.