International Journal of Coal Geology 50 (2002) 303–315

International Journal of
COAL
GEOLOGY

www.elsevier.com/locate/ijcoalgeo

Measuring, understanding and visualising coal characteristics—innovations in coal geology for the 21st century

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Accepted 29 June 2001

Abstract

For the coal industry to remain competitive into the 21st century, particularly if coal prices remain low, it is incumbent upon the industry to understand their products and use this knowledge to improve the efficiency, environmental performance and safety with which their products are mined, processed and used. A full understanding of coal characterisation empowers the user to achieve these goals. Areas where coal characterisation is of crucial importance include integrated gasification and combined cycle (IGCC) combustion, metallurgical uses, gasification, extraction of coal bed methane and liquefaction. Future coal characterisation research avenues are reviewed. For this understanding to be achieved, radical new analytical methods that are cost effective, avoid subjective judgement, can provide prompt online measurements and are meaningful in terms of performance prediction will be required. Examples of emerging technologies are presented. Visualisation of coal quality data and the coal chain has always been important to the coal mining community. Methods of building and maintaining databases, and simulating such data are reviewed.

Keywords: Coal characterisation; Conditional simulation; Analytical methods

1. Introduction

In coal mining, considerable effort and resources have been, and will continue to be, given to research and development. Prior to the radical oil price changes that started in 1973, R&D was driven by scientific interest. During the immediate post-1973 period, there were different economic pressures brought to bear as new and improved uses for coal were sought. This continued throughout the 1980s as the energy forecasts predicted oil at US$80 per barrel, zero electricity demand growth and chronic energy shortages (Mills, 1999). In the years since these forecasts were made, oil prices remain at or about US$20 per barrel, there has been a 70% increase in energy demand and, far from experiencing chronic shortages, there is a plentiful supply of conventional energy. The market for electricity has been such that 350 new power plants were required to supply these needs. As a result, in the 1990s, there is record production of coal (Fig. 1). This growth occurred at a time of increased competition, lowering coal prices and a demand for higher coal specification (Bonskowski, 1999). This resulted in R&D shifting emphasis in the 1990s to provide cost reduction in the work place and towards clean coal technologies (CCT).

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PII: S0166-5162(02)00122-2

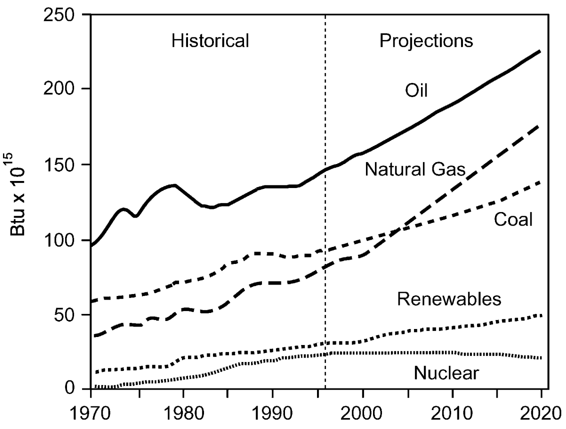

Fig. 1. World Energy Consumption Projections to 2020 (modified after National Energy Information Center, 1996, Fig. 11).

It is through R&D that new ideas are born, developed and tested as far as the pilot plant stage. The driving force for R&D is, and will probably continue to be, cost reduction. By improving efficiencies or introducing better technologies, at all stages of the coal mining process from exploration through extraction to coal processing, costs can be better controlled.

Innovation is something that is new or improved done by an enterprise to create significantly added value, either directly for the enterprise, or indirectly for its customers. In so doing, there is an opportunity to increase market share, create new markets, add new customers, improve productivity and enhance safety or environmental performance (Osborne, 1998).

The aims of each project, whether driven by R&D or innovation, can be achieved once there is a clear scientific understanding of the coal properties and the way coal behaves during utilisation. There is an implicit need to be able to measure these properties. Measurements are required from the exploration stage of collecting coal samples, through mining, treatment and handling to its ultimate usage, as well as determining the fate of its by-products. Thus, both coal characterisation and analytical methodology will be crucial in furthering our understanding of coal behaviour during mining, processing and utilisation. These data will be required in a readily accessible format and suitable software will also be required to visualise the data. New, improved and less expensive data storage and retrieval systems will be needed, as will data manipulation and visualisation software.

2. Building and maintaining electronic databases

Typical data collected and evaluated by coal companies include exploration geophysics, borehole data, coal quality and geology, followed by mine data that includes blastholes, quality control data, geotechnical and environmental data. Traditionally, these data have been collected on paper and transferred to electronic storage by manual means. Therein lies the potential for errors to be introduced. The future must lie in electronic data loggers and electronic data transfer. Laboratories are already emailing files of coal quality data to customers. Data loggers will be used more extensively to collect borehole and other geological and mine information, which in turn can be down loaded directly into specified tables in databases, either through a cable link to a PC or through wireless technology.

The strategy for collection and evaluation (checking) of data (Walters, 1999) is often a matter of company procedure. Each geologist and mining or processing engineer knows what the database should contain i.e. ranges, values, units, etc. It is a simple matter of setting up the validation tables to check that the data conform to the ranges, values and units, etc., expected.

Access to the data is the primary consideration. Should all data be available to all users? Almost any mine personnel should have access to the database for viewing and processing the data for resource estimation, mine design, scheduling, etc. Only designated personnel should be able to enter data and a very limited number of administrators should be able to edit the data. These administrators would be responsible for database management and version control.

Certain data require proprietary software, hardware and technical skills not shared by all users. Most electronic data are accessible by MS Word™ and Excel™. There is a wide range of general purpose data manipulation software available, such as Surfer™ (Golden Software, 1999), Origin™ (Microcal Software, 1999), etc. Most mines also have site-specific proprietary software, e.g. Datamine™, Vulcan™, MineSight™, Surpac™, Minex™, etc., intended for use only with specific data files or collections. Other operations may have task-specific proprietary software, such as Isatis, used for resource and/or reserve calculations, or Whittle products for strategic mine planning. In the future any database must be able to produce data that will be read by any third-party proprietary technical software product.

Evaluating and reviewing the data is essential. Normally, a single, maintained, flexible and secure storage source is recommended. This means that only the most recent copy of the database is being used for evaluation at the mine site. Multiple access to the database, even from multiple sites, can be achieved through web technology. The additional advantage of the web technology is that sets of data, each containing information about a particular item, such as a borehole, can be available through a single search interface.

Documentation for the database is essential: how are the data entered, in what format, etc. It is essential that adequate, long-term preservation and access is maintained.

Data that are collected should be sufficient to ensure that they are adequate for achieving measured status as defined under the JORC (1999) code. Data should be sufficient for the life of mine and for the market requirements at the mine design stage. The database should, therefore, be planned to contain all such data. For contingencies, it should be possible to add fields and columns to the database should there be additional information required at a later stage. Some data are not cumulative, such as ash fusion temperatures (AFT) and free swelling indices. The database should be capable of manipulating all data that can be 'cumulated.'

In the future, any coal research organisation or coal mining company will require a 'future-proof,' easily accessed, secure set of data.

3. Coal characterisation

It is clear that much energy is wasted despite the industry's ability to use coal more efficiently. Coal can also be burnt without producing particulates or contributions to acid pollution (Osborne, 1998). Cost reduction in the coal mining and utilisation industry can be achieved by improving efficiencies and reducing pollution. A clear understanding of the characteristics of coal and the products of coal combustion is, therefore, required.

In the 1970s and 1980s the world's major coal producers and users also had the largest government funded research budgets. In Europe, the largest providers of research funds in 1986 were Germany (US$160 M), the Netherlands and the UK. In the rest of the world in 1986, Australia (US$30 M), Canada (US$46 M), Japan (US$420 M), South Africa and USA (US$1300 M in 1980) funded the main research. By 1997, the reduction in government research funds and privatisation have led to significant changes to R&D facilities in Canada (US$4 M), Germany (US$3 M), Japan (US$180 M), Netherlands (Stamicarbon), UK (British Coal, CRE and MRE privatised) and USA (US$103 M) (Ishihara et al., 1999). Only Australia (US$29 M) appears to have retained a similar level of government supported research funding. Osborne (1998) estimates that some US$$10 \times 10^9$ has probably been withdrawn from R&D funds world wide during the 1990s. Many major projects have been stopped, some prematurely, and others reduced significantly. Competition for the remaining funds is fierce.

Part of the reduction in government spending has been driven by privatisation of many nations' power and coal industries. It is more difficult to gauge how much private companies are spending on R&D as they consider this information to be commercially sensitive.

Projects that are continuing are based upon successful coal characterisation research undertaken prior to these funding cuts. The success of emerging technologies, such as specialist fluidised bed combustion, and the potential of combined cycle generation is based upon coal characterisation studies.

Coal mining companies and utilities that wish to remain competitive have had to do their own research or pay research organisations to do directed research. This has brought producers, users and research organisations together into organisations, such as the Australian Cooperative Research Centre (CRC) and the British Coal Research Forum. These organisations are able to provide a united front when it comes to planning, monitoring and implementing research activities. They are also able to make collaborative applications for funding and investments in research projects.

The importance of surviving research centres maintaining contacts during this time of reduced funding is clear. Apart from publications and ubiquitous email communications, one vital means of disseminating information is at conferences. These include amongst many others, the Pittsburgh Coal Conference, the International Conference on Coal Science, the Australian Coal Science Conference and the European Coal Conference. Transferring technological information can also be achieved through presentations and workshops, arranged between interested parties, locally.

3.1. Low rank coal characterisation

Coal characterisation work in lignites/brown/subbituminous coals continues in the fields of combustion, gasification, briquetting and carbonisation. Such low rank coals are extracted in Australia, Germany, Greece, Thailand, Turkey and the USA, amongst others. Briquetting can increase the handleability of coal, but there is a cost. Either the coal needs to be investigated for inherent self binding or alternative, inexpensive, harmless and ubiquitous binders should be investigated.

The most significant areas of future research that have the highest potential rewards lie in the elimination of inherent moisture (devolatilisation) and desulphurisation (Doğan et al., 1999). The majority of low rank coals are consumed without any upgrading process. These coals typically have high moisture contents (15–50%), and consequently, low calorific values. New technologies and new processes are required that will upgrade these low-grade fuels to be more energy efficient and clean burning. Pioneering work into these processes include low temperature carbonisation, such as the K-Fuel® process (Gentile, 1995; KFx Net Power Solutions, 2001).

Desulphurisation is most difficult in run of mine coal. In coal where sulphur content is important, such as during combustion, retro-fitted flue gas dulsulphurisation is often an expensive solution. Alternative methods of desulphurisation will require investigation. Physical cleaning can remove some of the pyrite, but future research into the application of microwave radiation (Kingman and Rowson, 1998; Marland et al., 1998), low temperature carbonisation (Doğan et al., 1999) and the use of bacteria for desulphurisation of coal will continue. In the latter process, when coal washing takes place, bacteria can be mixed with the crushed coal. During subsequent flotation, improved pyrite removal has been demonstrated by Nagaoka et al. (1999).

3.2. High rank coal characterisation

Similar work in bituminous coal characterisation has centred on the needs of emerging technologies, and the economics and environmental demands of coal production and utilisation. Major uses of high rank coal where coal characterisation is of crucial importance include integrated gasification and combined cycle (IGCC) combustion, co-combustion, metallurgical uses, gasification, extraction of coal bed methane and liquefaction.

For the emerging technologies, research has focused on determination of reaction rates under conditions of high temperature and/or pressure. ETSU (1997) determined that there are several areas of research that would be necessary for the British coal industry to maintain its position in the pulverised coal combustion power generation industry. They showed how process issues, such as carbon-in-ash, flame stability, corrosion, ash deposition and stack emissions, are linked to market drivers. They determined that the sciences that underpin these process issues include coal science and coal characterisation.

Other work has been oriented towards quantifying the transformations of mineral matter in coal to ash or slag during combustion, gasification or liquefaction. Paterson (1998) also identified the need to understand the behaviour of blends used in power generation. He identified the need to understand and predict blend performance, particularly a blend's impact on reactivity, flame stability, carbon-in-ash and emissions. These process issues are also underpinned by coal science and coal characterisation.

Co-combustion, the combustion of a secondary fuel with coal, will also require investigation. There are numerous waste products that could be burnt. This in itself requires research to identify, understand and predict the impact of different waste mix blends' impact on reactivity, flame stability, carbon-in-ash and emissions (Maier, 2000). Part of these process issues are also underpinned by the characterisation of the coal to be used.

Metallurgical coke is predominantly used for the production of iron in blast furnaces. Knowledge of the petrography is more significant in metallurgical coal than in many other coals, although Trimble and Howe (2000) have shown there is a relationship between coal petrology and coal grindability. New technology, such as automated computer scanning for petrographic analysis, has significantly reduced the time and increased the reproducibility of results when compared to the previous manual point counting methods.

Measures of coke strength are also specific to metallurgical coals, so improved methods of measurement are constantly being sought.

Scott (1994) explains that the effect of reduced total demand and the decline in demand for some of the products of the blast furnace has been worsened by competition from the electric arc furnace process. In the longer term, new direct reduction processes are being developed which may provide additional competition for the blast furnace. In addition, many improvements have been made to reduce the environmental impact of the coking process. However, to maintain an economically attractive supply of coke further research is required. A number of routes to reduced coke consumption exist, but the injection of fuel into the lower part of the blast furnace is the process which appears to have the greatest potential in the short- to medium-term. Coal appears to be the most suitable injectant. Current coal injection technology is being researched. Future research will be directed towards characterising the coal for use as an injectant. This will help define the ultimate limits to the replacement of coke by coal injection.

Coal-bed methane extraction is of particular interest, locally to gassy underground mines, and to countries where there is a rapidly growing energy demand, such as China. Extraction quantities and rates are strongly influenced by the coal structure from the micro- to the macro-scale. This, too, is underpinned by coal science and coal characterisation.

3.3. Coal for the market

Basic coal characterisation is undertaken before coal is mined. This provides the information that the mine requires to blend run of mine (ROM) coal to ensure that a product is provided that suits the customer's needs. Other coal operations pass their coal through a washing (cleaning) plant. To plan and build a wash plant requires an understanding of the characteristics of the size distribution after crushing, and the washing characteristics. Once built and in operation, the wash plant becomes part of the coal chain (Fig. 2). The characteristics of the coal often change significantly between being mined (ROM) and being prepared for the market (washed and/or blended). It is essential that these changes are fully understood. This is achieved through coal characterisation. Continued understanding (quality control) is achieved through good and frequent sampling along the coal chain (Fig. 2).

Integrated gasification and combined cycle (IGCC) combustion is an emerging technology that may well be the successor to pulverised coal combustion (PCC) and, in UK, the aging Magnox nuclear power stations. The UK then faces a substantial loss in the mitigation of CO_2 emissions, preventing the UK government

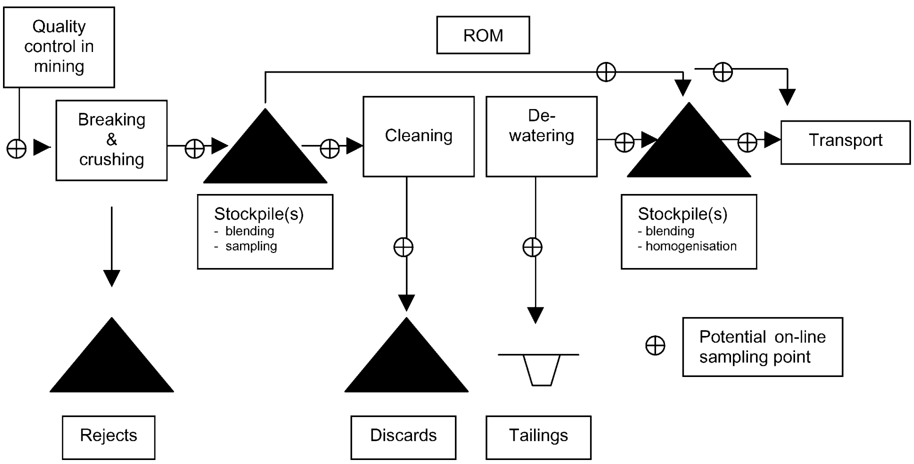

Fig. 2. Potential sites for online analysers in a typical coal chain (modified after Osborne, 1998).

from maintaining their promised reductions in carbon dioxide emissions. There is much current research on means of generating power from fossil fuels without having to discharge carbon dioxide to the atmosphere. One route is to remove the carbon dioxide from flue gases before release. This process is cumbersome and extremely expensive. A more practical solution is to first gasify the fossil fuel and remove the excess carbon dioxide before combustion.

The operational performance of the gasification process for IGCC plants in Europe has shown that increased and more detailed knowledge of the mineral matter in the coal is required. The vastly different operating conditions in IGCC plants have caused changes in the ways in which mineral matter reacts. This is an avenue that will require detailed investigation.

The mode of occurrence of trace elements in the mineral matter also requires investigation. The behaviour of trace elements in coal during combustion or gasification is partly dependent upon the mode of occurrence of the trace elements in the coal (Davidson, 2000). The modes of occurrence of trace elements in coal and coal combustion products also forms part of the coal characterisation process. Understanding their modes of occurrence is essential in order to model and predict the behaviour of trace elements during coal combustion, gasification or leaching of combustion products once they have been discarded. Such modelling provides information to enable proper evaluation of the potential impact that trace elements may have upon the environment, human and animal health and, therefore, the economic use of coal combustion products.

4. Analytical methods

Many methods for analysing coal properties were described and published by the British Standards (BS) organisation, American Society for Testing Materials (ASTM) and International Standards Organisation (ISO), etc. Some were written many years ago, since which time analytical methodologies have advanced. Several of these standard methods are outdated, too slow or unreliable.

Recent reports (ACARP, 1998; Paterson, 1998) have suggested that the whole coal industry should look at new analytical techniques that are cost effective, avoid subjective judgement, can provide prompt online measurements and are meaningful in terms of performance prediction. This would apply to areas, such as:

- coal utilisation (thermal and coking coal)
- resource estimation,
- coal bed methane,
- in-pit quality control,
- mine production monitoring,
- process control (including coal preparation, size degradation, fine coal cleaning, etc.)

Utilities have asked coal producers to look carefully at their coal in terms of it being a possible source of some elements of potential environmental concern. Some newer coal contracts already specify maximum values for potentially toxic trace elements in the whole coal; a significant change from only a few years ago.

There exist a number of methods for quantitative analysis of trace elements in whole coal. These are discussed in some detail by Davidson and Clarke (1996). This review looks at some of the more recent developments in quantitative analytical techniques, with a view to identifying further avenues of research.

4.1. Proximate and other analyses

Most exploration core, in-seam quality control sampling and coal shipment quality values are defined using proximate analyses. In the case of the former, the value of a project (potential mine) is based upon this information. In the latter two cases, the value of the shipment (revenue) may depend upon the results. The importance of taking representative samples from which accurate analyses are produced, cannot be stressed enough.

In exploration, the in situ coal quality values are based upon samples that have been treated in a number and variety of ways. It is important that this treatment is standardised to ensure that, for example, the in situ density and moisture content are correctly estimated (Preston and Sanders, 1993). Incorrect estimation of resources has occurred, particularly in low rank coals, due to incorrect estimation of density. Down-the-hole measurements and analytical techniques may be a potential research avenue for determining coal properties in situ in the 21st Century. This will aid the rapid and accurate evaluation of coal deposits.

These remote measurement techniques could be expanded to enable sensors attached to/built into drilling bits to enable drillers to follow nominated horizons more accurately. Other sensors could be built to monitor the performance of drilling equipment in all geological environments. These data could then be used to optimise the performance.

Moisture content is difficult to measure by a reproducible method. Moisture not only affects density estimation, but also handleability of coal during processing and transportation. Handleability also depends upon the amount of fines. These are also difficult to assess. In addition to the amount of fines, hardness, abrasiveness and grindability are also important characteristics that require determination. In the future it may be necessary to update these tests or even develop new tests as coal undergoes preparation for use in emerging technologies.

IGCC combustion is one such emerging technology. The operational performance of the gasification process for IGCC plants in Europe has shown that increased and more detailed knowledge of the mineral matter in the coal is required.

Some effort is being made, particularly in Australia, to update some of the analyses used in coal characterisation.

4.2. Laser ablation–ICP–MS

Inductively coupled plasma (ICP) photospectrometers have been used for a number of years to analyse the major and trace element contents of ash and even whole coal. Laser Ablation–Inductively Coupled Plasma–Mass Spectrometry (LA–ICP–MS) has enormous potential in coal characterisation research (Booth and Spears, 1999). Element concentrations are determined with limits of detection currently in the parts per billion range, and spatial resolution as low as 10 micrometers. It is now possible to analyse trace element concentrations of whole coals (bituminous), as well as individual minerals and macerals within the coal. Using this technique, potentially hazardous trace elements, such as As, Cd and Pb, can be detected, even in the low parts per billion concentration range. Analysing whole coal in this way minimises the errors that may be introduced during standard, whole coal digestion methods.

Booth and Spears (1999) point out that by automatically scanning a coal sample block and analysing at many tens of sites, a close approximation to a whole coal analysis of major and trace element concentration is achieved.

4.3. Energy dispersive polarised-XRF

Energy dispersive polarised-XRF (EDP-XRF) is not as expensive as a wavelength XRF (Spears et al., 1997; Spectro Analytical, 2001). EDP-XRF can analyse over 60 elements on pressed powders down to 1 ppm for most element and sub-ppm for the heavier elements. Time taken for each element is as low as 1 element per minute. Precision and accuracy are good when compared with standard reference coals. The use of pressed powder pellets leaves out the need for digestion. The speed of the analyses makes this a very attractive method for use in online analysers.

4.4. Online and automated analyses

In exploration, it may be possible to avoid the inconsistencies of empirical quality values associated with normal sample treatment and analysis. This can be achieved through the use of down-hole geophysical analytical tools. A more recent development, using natural gamma, is the Ash Probe (Taylor, 2000). This probe measures the in situ ash content of coal stockpiles. Further work using natural gamma and density measurements to determine in situ coal characteristics seems a likely productive area for future research.

One part of the coal chain where savings can be made is avoiding rehandle. In moving coal from the mine via stockpiles and coal preparation plants to transportation, online analysers offer the opportunity for continuous monitoring of coal quality (Fig. 2). Accurate and reliable quality feedback will enable mines to optimise quality control and produce well blended stockpiles that meet the customer's specification.

Current online analysers are also referred to as coal analysers. They measure the mineral matter component and/or moisture content of the coal. Other forms of online analysers being tested include size analysers on moving belts and ash/mineral matter analysers (Couch, 1996; Kirchner and Maude, 1994). Size analysers use image processing techniques to determine the distribution of particle sizes in a moving stream. This could give operators prompt warning of any defects in the crushers. Quantification of mineral matter content is usually based upon measurement of scattered or absorbed gamma or X-rays. Identification of minerals within the coal can be achieved using prompt gamma neutron activation analysis (PGNAA). If installed on ROM conveyors, PGNAA would provide data for quality control to assist the mine improve coal blending/product specification. PGNAA could also be incorporated into the product loading streams, thus providing a detailed indication of consignment consistency.

Techniques used to measure moisture content include capacitance, infrared reflectance, microwave, neutron transmission and nuclear magnetic resonance (NMR). Capacitance and microwave techniques are already in use. Methods that may become more widely used in the future include NMR and infrared. Magnetic resonance can be used for coal quality monitoring (Harmer et al., 1997) and infrared can be used to measure free moisture.

In the future, new generation online and offline analysers may be used to replace mine and port laboratories.

4.5. Predicting behaviour in use

Standard laboratory analyses for coal characterisation are inexpensive and easy to obtain. However, they frequently fail to predict how a coal will behave in its end use. Most coal is used in pulverised coal combustion (PCC). Recent tests have been developed to provide information for particular combustion processes. For example, atmospheric or high pressure differential thermogravimetric analysis (DTGA) uses a small amount of powdered whole coal to obtain a profile of the rate at which mass loss occurs. These profiles offer a method of predicting what will happen to coal during combustion in a full-scale plant.

The drop tube furnace (DTF) is being used to obtain more realistic assessments of the behaviour of pulverised fuel (PF) during the combustion process. New and improved versions of DTFs are appearing and their results are becoming more reliable and useful as predictors of conditions in commercial units (Godoy and Lockwood, 2001).

The nature of the mineral matter in the coal impacts directly upon the behaviour of ash during combustion. Computer-controlled scanning electron microscopy (CCSEM) has provided a tool with the ability to characterise the mineral matter in a sample of PF in respect of its chemical composition, size and degree of inclusion of individual minerals in coal particles. The data thus derived provide a means of assessing the potential impact of the mineral matter on power station performance. In addition to CCSEM, thermomechanical analysis (TMA) has provided a reliable means of assessing the ash fusion temperatures (CRC, 1999), as well as other coal ash and slag applications (Lucas et al., 2001).

4.6. Future trends

In the recent past, the majority of research efforts have been oriented towards clean coal technologies (CCTs). CCTs are those which facilitate the use of coal in an environmentally satisfactory and economically viable way. They are designed to meet various regulations covering emissions, effluents and residues. This research is needed to make the necessary environmental and efficiency improvements in coal utilisation. This also represents the major growth area in research. The eventual success of CCT research projects depends upon the extent to which coal characterisation research is able to provide the foundation upon which all of the CCT work is based. Without the coal characterisation work can the CCT be implemented? Only if the coal characterisation work is substantial enough will predictions on new technologies' performance be achieved quickly.

Environmental legislation will impact the manufacture of coke as much as it will the combustion of coal. A thorough knowledge of the types and quantities of major and trace elements in the 'whole' metallurgical coal, as well as its other characteristics, will be required. Compliance with environmental legislation can be achieved, not only through improved technology, but also by using the knowledge gained from coal characterisation.

As research improves the technologies being used in the new generation online and offline analysers and research into coal properties increases our knowledge, these analyser systems may well be used to replace mine and port laboratories.

Other techniques may become commercially available, such as proton-induced gamma ray/X-ray emission (PIGE/PIXE). These are nondestructive methods of analysis of whole coal, but require a particle accelerator to generate the beam of protons (Davidson and Clarke, 1996). PIGE/PIXE requires a very small sample (1 to 10 micrograms), but the detection limits are less sensitive than atomic absorption spectroscopy or ICP methods. Further work is required in this field before it will make a significant impact on coal characterisation.

5. Software simulation

Many problems can be address using software to simulate and optimise in coal mine geology terms. These include simulating coal qualities and coal impurities, achieving better estimates of coal resources in the ground, simulating life-of-mine (LOM) quality variations and blending and scheduling optimisation. Future research into simulation methodologies should extend to include coal handling and coal processing.

5.1. Estimating coal qualities and resources

Coal estimation methods are described by Ruppert et al. (2002). They also explain what the future trends in estimation methodologies are likely to be. These estimation methodologies are becoming important, not only for public reporting by companies, but also to the individual (competent person) who is responsible for those results under the JORC Code (JORC, 1999).

The JORC Code sets out a system for classifying tonnage and coal quality estimates as either reserves or resources, and for subdividing these into categories that reflect different levels of confidence. The purpose of this is purely for public reporting. JORC does not regulate how estimates should be done, nor does it attempt to quantify the amount of data needed for each resource category. This must be decided by the Competent Person (often the mine geologist) based on direct knowledge of the deposit in question. The criteria used may be entirely subjective or they may involve some

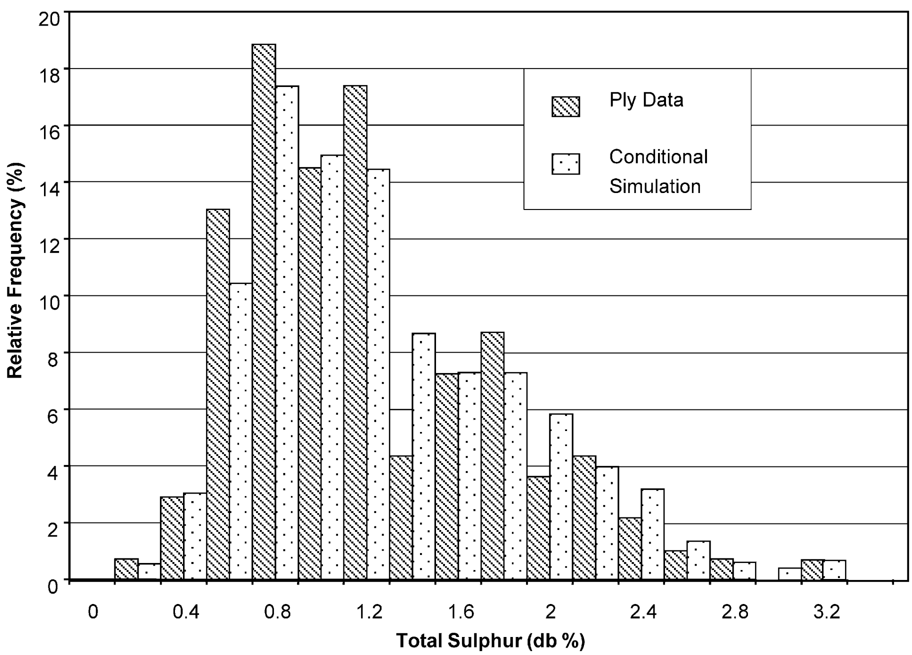

Fig. 3. Histogram illustrating how conditioning of simulated sulphur data (db) by seam quality data can achieve a similar statistical distribution.

quantitative measures, or mixtures of both. There are no prescribed methods that can be applied. It is very important that the selected methods of distinguishing resource classes should be geologically sensible in the context of the deposit being studied.

As the JORC Code, or one of the many codes that emulate the JORC Code, becomes the standard method of reporting resources to the local Stock Exchange, the Competent Person must become familiar with new (and improved?) methods of resource estimating.

5.2. Life of mine quality variability

Some coal quality variables, such as ash and calorific value, have large numbers of data points. There are often fewer points with sulphur or trace element data. This creates estimation problems and difficulties in estimating life of mine coal quality variability.

Coal quality specification plays an important part in the negotiation of a coal supply agreement. Predictions of the variability of sulphur and ash contents and calorific value on a daily and weekly basis have been identified as the most significant parameters affecting coal supply. Two phases of work are used to generate predictive models of likely coal quality variability. The first phase provides approximations of the average sulphur and ash contents over daily and weekly production periods.

The second, more extensive phase of work generates detailed, simulated sulphur and ash models for each seam or ply, on a very fine grid. These models can then be ‘mined’ in a manner that mimics the proposed mining method. The variability in sulphur and ash content in the ROM coal feed for the life of the mine can then be predicted on the basis of the production scheduled derived from the ‘mined’ models (Chica Olmo and Laille, 1984). The simulated values are controlled, or conditioned, by drill hole samples which gives rise to the name of this technique, Conditional Simulation (Deutsch and Journel, 1992). Lack of data for some of the layers within a

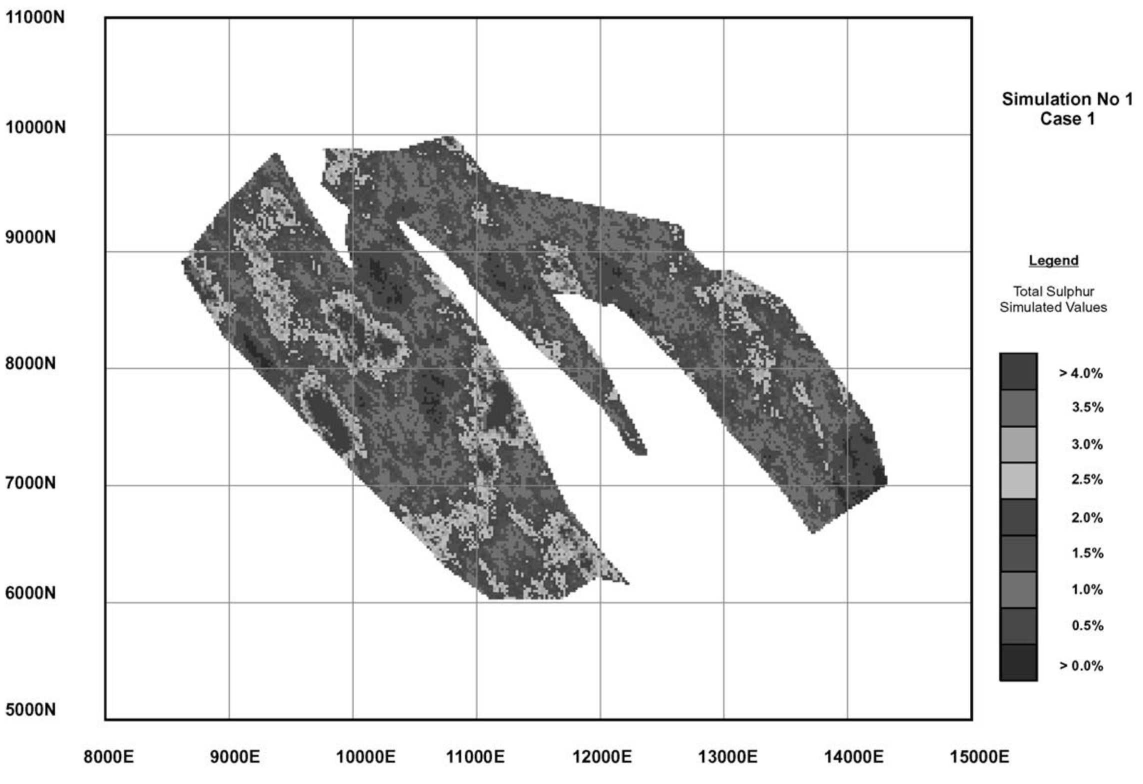

Fig. 4. Illustration of conditional simulation of total sulphur (db) for use in mine planning.

model presents problems to the estimator for the application of the method. This is particularly true for sulphur values within some plies when less than thirty samples of hard data are available for each layer. Adapting the conditional simulation technique, by using the more abundant, but less reliable whole seam data (soft data) to augment the ply data, can mitigate this problem. Conditional simulation models, thus, generated still need to be carefully examined and verified. Once they are found to satisfactorily replicate the geological, statistical (Fig. 3) and geostatistical characteristics of raw data, the simulated quality variability can be used for predicting LOM coal feed (Fig. 4).

5.3. Blending and scheduling optimisation

There is an increasing trend towards using coal quality parameters in computer models for life of mine blending and scheduling optimisation. This is employed to predict how best to develop a mine for a particular resource. Typically this is achieved by estimating the cash flow generated by mining the deposit in sequence A and comparing this to sequence B, C, D, etc. The sequence that generates the greatest cash flow (converted to Net Present Value) is taken as the optimal solution.

Similarly, simulations can be used to predict the performance of a proposed new blend and the effects of changing the feedstock. This is of particular importance where the proposed blend is to be used in pulverised coal combustion or blast furnace operation, where there is a wealth of background information against which to validate such models.

Blending at the mine can also have significant impact on daily production. If the ROM coal can be extracted and stockpiled in such a way that the correct blend quality is achieved, then there will be increased efficiency at the mine. There will be less rehandle and fewer potential penalties will be incurred for delivering a non compliant product.

6. Project reviews

Reviews of projects or procedures give checks and balances for 'best practice.' Reviews can, therefore, add value by transferring best practice between Groups or between operations within a Group. By having reviews carried out by external consultants or peers, best practice is brought into the Group or operation from outside. Senior personnel who have previously been uninvolved with the project or operation usually carry out reviews. They tend to occur more frequently on the larger, and, therefore, riskier, projects. A similar procedure already exists within the scientific community where peer reviews take place before publication of new or interesting research.

7. Conclusions

Prior to the oil crises that initiated in 1973, R&D was driven by scientific interest. During the immediate post-1973 period government funding of R&D increased in an attempt to develop coal conversion technologies that would reduce the dependence on imported oil. The risk of severe oil shortages has now subsided and R&D has shifted emphasis in the 1990s to provide cost reduction in the work place and towards CCT. Unfortunately there has also been a dramatic reduction in government funding of coal related research.

For coal to be accepted as a fuel for the future, CCT will be required to enhance efficiency and reduce the environmental impact of emissions. A clear understanding of the characteristics of coal, and the products of coal combustion and coke manufacturing is, therefore, required. It is at this basic level that research is still required. Much of the research funded by private industry is directed towards avenues that should have an impact upon their operations. Government funding is still required for non directed research.

The main areas where future research is required include analytical methods, the input of these methods into new international standards and computer simulation.

No coal characterisation project will be successful without reliable measurements. Reliable measurements provide the key to understanding how coal behaves in various end uses. Accurate, reliable analytical methods will be required to ensure that progress continues in coal characterisation research. Once the data are collected, reliable and secure data storage is required. Researchers must also be familiar with the various end uses of coal to ensure that the correct data are collected. This work will require funding from governments, coal suppliers and coal users alike.

Research into 'remote' methods of measuring, analysing and characterising coal will also provide much fruitful research. Improved analytical methods should lead to lower detection limits of minor and trace elements on a whole coal basis. Improvement in analytical methods should also lead to improved online analysers. This in turn has potential for feeding back information into the control loop to improve quality control at mines sites and all points down the supply chain where stock piles are required.

Once the results from new analytical methods show correlation with behaviour in use, they could be implemented as new international standards. New standards could also include improved sampling of coal and handling of coal samples.

Computer simulation of in situ coal quality for improving predictions of the variability of sulphur and ash contents, and calorific value on a daily and weekly basis have been identified as the most significant parameters affecting coal supply. Future research into simulation and modelling of coal treatment, coal handling and end use should also be addressed.

Acknowledgements

The permission of Rio Tinto to publish this paper is gratefully appreciated. The author wishes to express his gratitude to Rio Tinto Technical Services for permission to prepare this paper and also to colleagues for their assistance and advice in the preparation of the manuscript. Thanks too for the constructive advice given by Drs. Crelling, Hower and Querol.

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