South African coal and its abrasiveness index determination: An account of challenges.

N. Tshiongo* **and A. Mulaba-Bafubiandi**

University of Johannesburg, Faculty of Engineering and the Built Environment, School of Mining, Metallurgy and Chemical Engineering, Department of Metallurgy, Minerals Processing and Technology Research Centre, South Africa, POBOX 526, Wits 2050, South Africa

Industry end users of coal like electricity generating stations have specifications on coal required in terms of reactive, chemical and physical properties; this includes the ash content, moisture, composition, hardgrove grindability index and abrasiveness index amongst many other properties. These properties affect each other including the overall coal properties and performance required during its specified usage. Some South African coals are known to be very abrasive, this causes operational challenges during the electricity generation combustion process as the coal abrades the plant equipment at a faster rate. Various South African coal samples were tested for abrasiveness index using the Yancey, Geer and Price (YGP) method. Results from these tests showed a lack of repeatability and reproducibility on the abrasiveness index values of coal samples. This lack of repeatability and reproducibility was observed in all coal samples tested. The same was found when either the same sample was tested in different laboratories or even when a mother sample was divided and tested repeatedly in one laboratory. Proximate and Ultimate analysis were conducted on the same South African coal samples for coal characterisation and classification. The size of the analysed sample; the size and shape, the degree of liberation of the abrasive coal component, and the interface between the abrasive component of coal and the blade surface are additional contributing factors. This study gives an account of challenges experienced and observed during the abrasiveness index determination of different South African coal samples. An attempt to holistically integrate the impact of main coal components contributing to the abrasiveness of coal will be presented.

Key words: Coal, abrasiveness index, Coal properties, holistic integration, coal composition,

1. INTRODUCTION

Coal is composed of two main groups of materials, the organic matter and the inorganic matter. The organic matter also known as the maceral components are the part that defines the coal and its value in different utilization processes, and the inorganic matter also known as the mineral matter does not contribute anything to the value and utilization of coal; it is however the cause of unwanted abrasion, corrosive and erosive behaviour of coal (Ward, 2002).

South African coals are mostly of low quality with a significant amount of incombustible mineral matter. They are typically medium rank C bituminous coals rich in inertinite and contain high mineral matter content (Malumbazo, et al., 2012). General classification of coal samples can be done, but the actual quantitative proportions, modes of occurrence of mineral matter vary from one coal sample to the other. In South Africa 75% of electricity is generated from coal with ESKOM burning 110 million metric tons of coal in 2012. Power generation using coal is an expensive process, with the major share of cost being spent in mining and preparation stages (Papanicolaou, et al., 2004). The composition of the coal supplied to the power generation plant is reflected by the damage to coal handling machinery, weir of boilers, pulverising mills and other units of the plant

* Corresponding author. Tel.: +27(0) 11 559 6162 E-mail address: n.tshiongo@gmail.com

(Bandopadhyay, 2010), (Wells, et al., 2005), (Wells, et al., 2004) & (Moumakwa & Marcus, 2005). This leaves the effectiveness of coal combustion as the remaining process of cost savings and this requires a thorough understanding of the effect of coal quality parameters (Ward, 2002), (Wells, et al., 2005), (Choudhury, et al., 2008), (Oman, et al., 2001) & (Van Dyk, et al., 2009) that affects electricity generation.

There are different criteria of classifying coal properties and quality depending on the influential factors like the coal rank, coal composition, coal mechanical and physical properties etc. (Oman, et al., 2001). Coal quality is specified in heating value, ash content, moisture and sulphur content, with additional properties like volatile matter, fixed carbon, ash fusion temperatures, grindability, abrasiveness index etc. The effects of the above coal quality properties includes fouling, slagging, abrasion, erosion and corrosion inside and on the parts of the electricity generation equipments which then affects the overall efficiency of the process.

Abrasiveness index of coal is affected by those minerals that are harder than steel like quartz and pyrite (Wells, et al., 2005)& (Wells, et al., 2004). Although nearly as hard as quartz, the abrasion- and erosive-weir damage caused by pyrite is significantly less than that caused by the same quantity of quartz (Bandopadhyay, 2010). Previous studies (Wells, et al., 2005) indicates that quartz is two to five times more abrasive than pyrite, and this was attributed to quartz being found as large and free particles whereas pyrite is often included in soft clays and coal matrix (Wells, et al., 2005)& (Wells, et al., 2004). But this was not proven to be true on worldwide coals and abrasive weir has also been linked to other variables like particle size and shape and also degree of inclusion (Wells, et al., 2005) as these can differ from one coal to the other (Wells, et al., 2004).The current work focuses on the investigations of abrasiveness index of South African coals, the effect that quartz and pyrite have on the abrasiveness index value and also give an account of challenges that were experienced in this investigation.

2. METHOD

2.1 Coal characterisation and classification

Different South African coals from various collieries around the country are used for this work. Proximate and ultimate analyses were done on all coal samples. The results were then used to classify and characterised coal samples from different areas into different groups according to their physical and chemical properties. These results were compared with results obtained from various international and national previously conducted researches on characterisation of various South African coals.

2.2 Abrasiveness index determination

Abrasiveness index of South African coal samples are identified using YGP method. This is done by placing 4kg of coal sample in a mill and mechanically rotating the sample with a steel blade of a certain mass and shape that stir up the sample during rotation. The weight of the blade is measured before and after stirring up the coal sample. Abrasiveness Index is the measure of how the coal sample abrades the equipment during its utilization in electricity generations, and this value is measured by the change in mass loss of the steel blade. Abrasiveness Index of coal is then measured in milligrams of weir blades per kilograms of coal processed.

3. RESULTS

3.1 Characterisation of South African coals

South African coals are classified as “High Volatile Subbituminous C” using different properties in previously done researched both nationally and internationally, but they do not specify the list of important parameters that determines the actual group of characterisation. On this work some of the values identified for coal parameters are not on the general coal properties range for South African coal rank as averages on the values are used. All the coals listed on the table below are classified as high volatile bituminous coal, but in most of them the value ranges for parameters is stretched too wide.

Table 1: Coal characterisation as previously reported and according to the current study.

Coal analysis (wt% dry basis)	Ranges for subbituminous C	Coal1 (from Int)	Coal 2 (from Int)	Coal 3 (Witbank)	Coal4 (Natal)	Coal 5 (Ermerlo)	From this work (Ave)
Proximate analysis							
Ash		13.70	16.68	12.1	15.5	10.0	20.88
Volatile Matter	46 - 42%	34.94	22.85	33.6	12.2	33.8	31.86
Fixed Carbon		51.36	60.85	51.8	70.4	49.6	43.47
Ultimate analysis							
Carbon	76 - 78%	70.22	68.1	82.3	86.5	78.8	80.21
Hydrogen		4.90	3.49	5.3	4.1	5.0	5.52
Nitrogen		1.39	1.69	2.0	2.3	1.1	1.60
Total Sulphur		1.01	0.54	0.8	1.5	0.3	0.67
Oxygen	12%	8.78	7.47	9.6	5.6	14.8	11.99
Moisture	12 - 18%	-	2.44	2.5	1.9	6.6	3.79

3.2 Effect of quartz content on the abrasiveness index of South African coals.

Quartz is the most common mineral in coal, and it occurs as angular to semi rounded grains that occasionally form clusters, making it more abrasive to electricity generating equipment components. Quartz fills cracks (Ward, 2002), forms lenses, encrustates or impregnates coal fragments, and even forms silicified pipes (Vassilev & Vassileva, 1996), giving clear access of quartz to equipment as it will be on the edges of coal particles. Quartz provides coal with an abrasive property due to its hardness (Bandopadhyay, 2010) and it contributes more as it is the most abundant mineral matter in coal

[1] (I. Prieto-Fernandez, 2002), [2] (J. Barroso, 2006), [3] (Vassilev, et al., 2009) ,[4] (Vassilev, et al., 2009), [5] (Vassilev, et al., 2009)

which in this case, the degree of liberation would have less effect on the relationship with abrasiveness index.

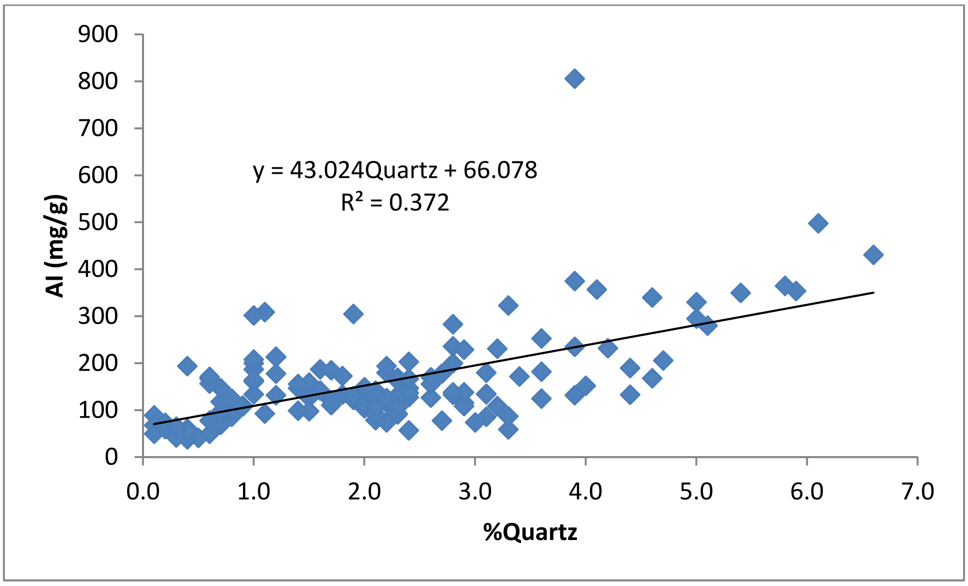

Figure 1: The effect of quartz content on the abrasiveness index (AI) values of South African coal.

Abrasiveness index of random quartz content coals was identifies and plotted on a graph to see how AI is affected by the quartz content. The figure above show the relationship between AI and quartz content of the Witbank South African coal samples. The AI shows a positive relationship with quartz with a very broad but positive trend in the plot. But the correlation between the two properties is very low at 0.37; this is an indication that there are other factors apart from quartz that affect the value of the AI.

3.3 Effect of pyrite content on the abrasiveness index of South African coals.

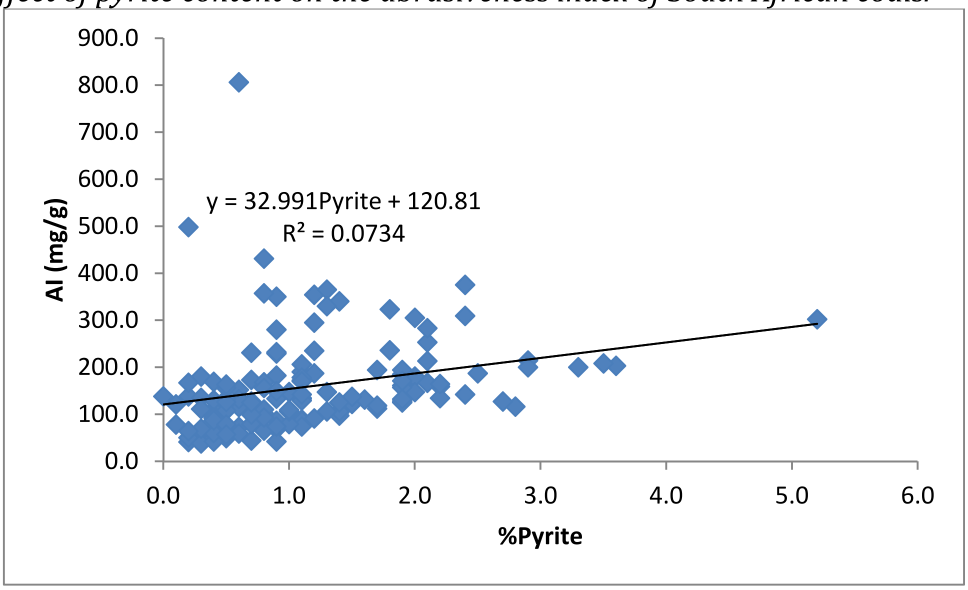

Figure 2: The effect of pyrite content on the abrasiveness index (AI) values of South African coal.

AI was measured at random pyrite content coal as it was done for quartz and the data is represented on the graph. The figure above show the relationship between AI and pyrite content of the Witbank

South African coal samples. The two variables have a positive relationship as indicate by the positive slope, but their relationship trend is too broad. The correlation between AI and pyrite content is low at 0.07 and if it is compared with that of quartz at 0.37 it can be clearly be depicted that quartz has more effected on the abrasive behaviour of the Witbank coals that pyrite. This can be attributed to the differences in occurrences of pyrite, which is entrained in the coal particle and does not have direct contact with electricity generation equipment. The relationship with the AI would be changed depending on the degree of liberation as this would help expose pyrite; resulting in a direct contact with the metal blades and a high AI.

3.4 Relationship between ash content and the abrasiveness index of South African coals.

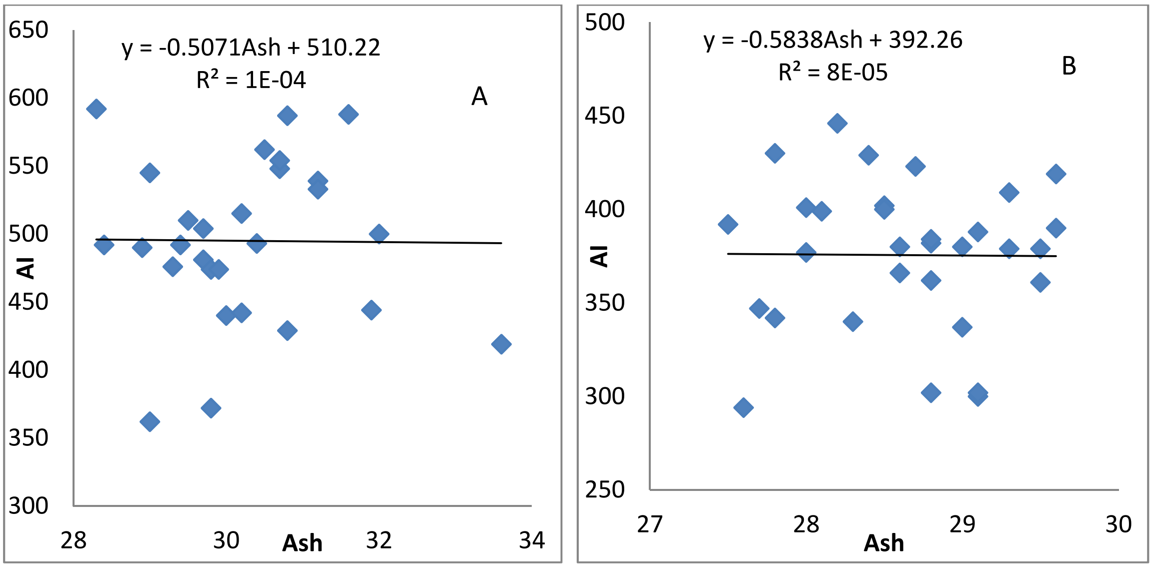

Figure 3: The relationship between coal ash content and abrasiveness index (AI) of South African coals.

The effect of ash content on the AI was investigated by determining the AI value at different and random ash content of South African coals. The results were plotted as shown on the figure above. The ash content has little effect on the AI of coal; AI values are on the same range despite the increase in ash content. The correlation of the two properties is closer to zero indicating the constant AI range on all ash content values.

3.5 Repeatability and reproducibility of abrasiveness index value

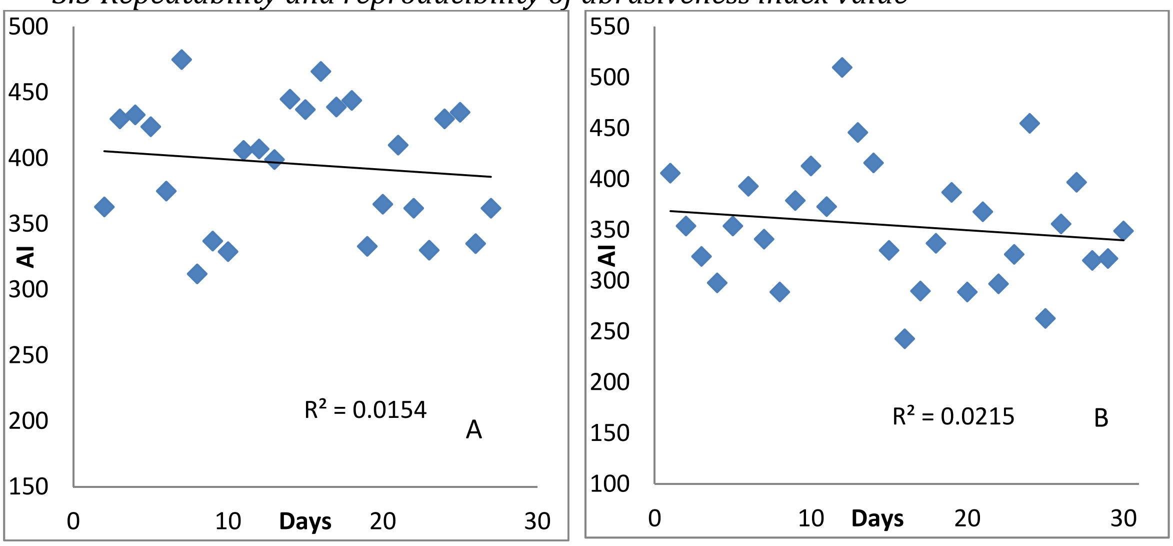

Figure 4: Presentation of abrasiveness index (AI) repeatability and reproducibility.

AI of the same coal was determined each day for a period of 30 days to assess the repeatability of the value. The figures above shows the lack of repeatability on the values of AI and the lack of reproducibility is presented by the R^2 value. The R^2 value for an ideal repeatability and reproducibility index should be zero which would represent the same AI value even when the measurements were done in different days. This behaviour can also be affected by the weir of the steel blade as it would be used repeatedly and the shape and contact with the coal sample will change and can result in changes on the milling and mechanism. The moisture content prior and after AI is not documented when there is also some moisture lost during transportation and handling of coal. Figure A and B are tests that were conducted in two laboratories. There has not been an indication of storage conditions (time and atmospheric conditions) that was employed before the AI test was done as oxidation can also affects coal properties and these properties affect the resulting AI value. This can also be the reason for lack of repeatability in the AI values. There are common variations that can be souses of lack of repeatability on the AI value when the tests are done in different laboratories. All experimental conditions are to be documented to make sure different laboratories are using the exact methods of determining the AI.

4. CONCLUSION

South African coals are subbituminous C coals with different properties as there are different coalfields in the country, and this provides different values for property analysis. There is a clear and visible indication of quartz having a more effect on the AI value than pyrite on South African coals but more investigation on the positioning of these phases in a coal particle can assist in understanding the relationship better. The results obtained shows that there is no relation between the ash content and AI on South African coal samples that were used for this study. There are challenges when it comes to AI determination and reasons behind the lack of repeatability and reproducibility of South African coals. A good correlation can be made comparing the same sample measurements that are done simultaneously using the same steel blades in terms of weir, size and shape. Clear documentation of experimental setup and methods are required to determine the difference in the AI values.

Acknowledgement

The Authors would like to thank everybody who assisted in data collection and sharing their input on this work. All is noted and greatly appreciated.

Bibliography

Alastuey, A. et al., 2001. Geochemistry, mineralogy, and technological properties of the main Stephanian (Carboniferous) coal seams from the Puetollano Basin, Spain. *International journal of coal geology,* Volume 45, pp. 247-265.

Bandopadhyay, A. K., 2010. A study on the abundance of quartz in thermal coals of India and its relation to abrasion index: Development of predictive model for abrasion. *International Journal of Coal Geology,* pp. 63-69.

Barroso, J., Ballester, J., Ferrer, L. M. & Jimenez, S., 2006. Study of coa ash deposition in an entrained flow reactor: Influence of coal type, blend composition and operating conditions. *Fuel Processing Technology,* Volume 87, pp. 737-752.

Casal, M. D. et al., 2003. Modifications of coking coal and metallurgical coke properties induced by coal weathering. *Fuel Processing Technology,* Volume 84, pp. 47-62.

Chou, C.-L., 2012. Sulfur in coals: A review of geochemistry and origins. *International Journal of Coal Geology,* pp. 1-13.

Choudhury, N. et al., 2008. Influence of rank and macerals on the burnout behaviour of pulverised Indian coal. *International Journal of Coa Geology,* Volume 74, pp. 145-153.

Choudhury, N. et al., 2008. Influence of rank and macerals on the burnout behaviour of pulverized Indian coal. *International Journal of Coal Geology,* pp. 145-153.

Demirbas, A., 2002. Demineralisation and dessulphurisation of coals via column froth flotation and different methods. *Energy Conversion and Management,* Volume 43, pp. 885-895.

Govender, A. & Van Fyk, J. C., 2003. Effect of wet screening on particle size distribution and coal properties. *Fuel,* pp. 2231-2237.

Hackley, P. C., Warwick, P. D. & Gonzalez, E., 2005. Petrology,mineralogy and geochemistry of mined coals,western Venezuela. *International Journal of Coal Geology,* pp. 68-97.

Hampartsoumian, E. et al., 1998. Evaluation of the chemical properties of coals and their maceral group constituents in relation to combustion reactivity using multi-variate analyses. *Fuel,* pp. 735-748.

I. Prieto-Fernandez, J.-C. L.-G. a. M. A., 2002. Determination of moisture in coal, in the case of discontinuous transport, using condensers. *Fuel Processing Technology,* Volume 75, pp. 129-140.

J. Barroso, J. B. L. M. F. a. S. J., 2006. Study of coa ash deposition in an entrained flow reactor: Influence of coal type, blend composition and operating conditions. *Fuel Processing Technology,* Volume 87, pp. 737-752.

Kolker, A., 2012. Minor element distribution in iron disulfides in coal: A geochemical review. *International Journal of Coal Geology,* Volume 94, pp. 32-43.

Krystyna, J., Kruszewska & Du Cann, V. M., 1996. Detection of the incipient oxidation of coal by petrographic techniques. *Fuel,* pp. 769-774.

Left, R. G. & Ruppel, T. C., 2004. Coal, Chemical and Physical properties. *Encyclopedia of energy,* Volume 1, pp. 411-423.

Lester, E. & Kingman, S., 2004. The effect of microwave pre-heating on five different coals. *Fuel,* Volume 83, pp. 1941-1947.

Liu, K., Yang, J., Jia, J. & Wang, Y., 2008. Desulphurisation of coal via low temperature atmospheric alkaline oxidation. *Chemosphere,* Volume 71, pp. 183-188.

Mahlaba, J. S., Kearsley, E. P. & Kruger, R. A., 2011. Physical,chemical and mineralogical characterisation of hydraulically disposed fine coal ash from SASOL Synfuels. *Fuel,* pp. 2491-2500.

Malumbazo, N., Wagner, N. J. & Bunt, J. R., 2012. The petrgraphic determination of reactivity differences of two South African inertinite-rich lump coals. *Journal of analytical and applied pyrolysis,* Volume 93, pp. 139-146.

Malumbazo, N., Wagner, N. J. & Bunt, J. R., 2012. The petrographic determination of reactivity differences of two South African inertinite-rich lump coals. *Journal of Analytical and Applied Pyrolysis,* pp. 139-146.

Maphala, T. & Wagner, N. J., 2012. Effects of CO2 storage in coal on coal properties. *Energy procedia,* pp. 426-438.

Marzec, A., 2002. Towards an understanding of the coal structure:a review. *Fuel Processing Technology,* pp. 25-32.

Mastalerz, M., Solano-Acosta, W., Schimmelmann, A. & Drobniak, A., 2009. Effects of coal storage in air on physical and chemical properties of coal and on gas adsorption. *International Journal of Coal Geology,* Volume 79, pp. 167-174.

Mishra, S. B., Langwenya, S. P., Mamba, B. B. & Balakrishanan, M., 2010. Study on surface morphology and physicochemical properties of raw and activated South African coal and coal fly ash. *Physics and Chemistry of the Earth,* Volume 35, pp. 811-814.

Mishra, S. B., Langwenya, S. P., Mamba, B. B. & Balakrishnan, M., 2010. Study on surface morphology and physicochemical properties of raw and activated South African coal and coal fly ash. *Physics and Chemistry of the Earth,* pp. 811-814.

Moran, A., Cara, J., Miles, N. & Shah, C., 2002. Biodesulphurization of coal: behaviour of trace elements. *Fuel,* Volume 81, pp. 299-304.

Moumakwa, D. O. & Marcus, K., 2005. Tribology in coal-fired power plants. *Tribology International,* pp. 805-811.

Moumakwa, D. O. & Marcus, K., 2005. Tribology in coal-fired power plants. *Tribology International,* Volume 38, pp. 805-811.

Nascu, H. I., Comsulea, D. I. & Niac, G., 1995. The distribution of inorganic elements between coal and mineral matter in Rumanian lignite. *Fuel,* pp. 119-123.

Oman, J., Senegacnik, A. & Dejanovic, B., 2001. Influence of lignite composition on thermal power plant performance Part 1: Theoretical survey. *Energy Conversion and Management,* pp. 251-263.

Ozer, C. E. & Whiten, W. J., 2012. A multi-component appearance function for the breakage of coal. *International Journal of Mineral Processing,* pp. 37-44.

Papanicolaou, C., Kotis, T., Foscolos, A. & Goodarzi, F., 2004. Coals of Greece: a review of properties, uses and future perspectives. *International Journal of Coal Geology,* pp. 147-169.

Pollock, S. M., Goodarzi, F. & Riediger, C. L., 2000. Mineralogica and elemental variation of coal from Alberta, Canada: an example from the No. 2 seam, Genesee Mine. *International Journal of coal geology,* Volume 43, pp. 259-286.

Prieto-Fernandez, I., Luengo-Garcia, J.-C. & Alonso, M., 2002. Determination of moisture in coal, in the case of discontinuous transport, using condensers. *Fuel Processing Technology,* Volume 75, pp. 129-140.

Sato, K. et al., 1996. Breakage of coals in ring-roller mills Part I.The breakage properties of various coals and simulation model to predict steady-state mill performance. *Power Technology,* pp. 275-283.

Strugnell, B. & Patrick, J. W., 1996. Rapid hydropyrolysis studies on coal and maceral concentrates. *Fuel,* pp. 300-306.

Su, S., Pohl, J. H., Holcombe, D. & Hart, J. A., 2001. A proposed maceral index to predict combustion behavior of oal. *Fuel,* pp. 699-706.

Tinkner, D. & Majer, R. W., 2005. *Design considerations for pulverised coal fifed boilers combusting Illinois basin coals.* Chicago, Illinois, USA, s.n.

Tsuji, H., Shirai, H., Matsuda, H. & Rajoo, P., 2011. Emission characteristics of NOx and unburned carbon in fly ash on high-ash coal combustion. *Fuel,* pp. 850-853.

Van Dyk, J. C., Benson, S. A., Laumb, M. L. & Waanders, B., 2009. Coal and coal ash characteristics to understand mineral transformations and slag formation. *Fuel,* pp. 1057-1063.

Vassilev, S. V., Kitano, K. & Vassileva, C. G., 1996. Some relationships between coal rank and chemical and mineral composition. *Fuel,* Volume 75, pp. 1537-1542.

Vassilev, S. V., Kitano, K. & Vassileva, C. G., 1996. Some relationships between coal rank and chemical and mineral compositions. *Fuel,* pp. 1537-1542.

Vassilev, S. V., Kitano, K. & Vassileva, C. G., 1997. Relations between ash yield and chemical and mineral composition of coals. *Fuel,* pp. 3-8.

Vassilev, S. V. & Vassileva, C. G., 1996. Occurance,abundance and origin of minerals in coals and coal ashes. *Fuel Processing Technology,* pp. 85-106.

Vassilev, S. V. & Vassileva, C. G., 2009. a new approach for the combined chemical and mineral classification of the inorganic matter of coal. 1. Chemical and mineral classification systems. *Fuel,* Volume 88, pp. 235-245.

Vassilev, S. V., Vassileva, C. G., Baxter, D. & Andersen, L. K., 2009. A new approach for the combined chemical and mineral classification of the inorganic matter in coal.2.potential applications of the classification systems. *Fuel,* pp. 246-254.

Ward, C. R., 2002. Analysis and significance of mineral matter in coal. *international Journal of coal Geology,* Volume 50, pp. 135-168.

Ward, C. R., 2002. Analysis and significance of mineral matter in coal seams. *International Journal of Coal Geology,* pp. 135-168.

Wells, J. J. et al., 2004. The relationship between excluded mineral matter and the abrasion index of a coal. *Fuel,* Volume 83, pp. 359-364.

Wells, J. J. et al., 2004. The relationship between excluded mineral matter and the abrasion index of coal. *Fuel,* pp. 359-364.

Wells, J. J. et al., 2005. The nature of mineral matter in a coal and the effects on erosive and abrasive behaviour. *Fuel Processing Technology,* pp. 535-550.

Wells, J. J. et al., 2005. The Nature of mineral matter in coal and the effects on erosive and abrassive behavior. *Fuel Processing Technology,* Volume 86, pp. 535-550.