Characterization of potential acid leachate from raw coal, discard coal, and slimes from a Colliery in the Witbank Coalfield, Mpumalanga Province, South Africa

Ntshengedzeni Obed Novhe[1], Jannie Maree[2], Jason Samuel Ogola[3]

[1]Council for Geoscience, Environmental Geosciences, 208 Pretoria, Silverton, 0001
onovhe@geosciences.org.za
[2]Tshwane University of Technology, Department of Environmental Water and Earth Science, Tshwane University of Technology, mareej@tut.ac.za
[3]School of Environmental Sciences, University of Venda, Private Bag X5050, Thohoyandou 0950, ogolaj@univen.ac.za

Abstract Geochemical static and kinetic tests were conducted on raw and discard coal and slimes from a colliery in the Witbank coalfield, to characterize the potential leachate. Raw coal was found to be potential non-acid producers, whereas discard coal had the potential to produce acid. Based on column leaching tests, raw coal and slimes did not produce significant leachate, whereas discard coal produced acidic and sulphate rich leachate, especially at the initial stages of experiment, followed by cyclic buffering. The study recommended that there should be long-term environmentally acceptable strategies to treat discard coal in order to meet the regulatory requirements.

Keywords Witbank coalfield, raw and discard coal, slimes, static and kinetic tests, leachate

Introduction

An integral part of a mining project is the consideration of environmental impacts, particularly, acid mine drainage (AMD). The legacy of mining continues to affect the natural environment, such as surface and groundwater resources, agricultural soil, fauna and flora, long after mining operations have ceased (Arnesen and Iversen 1997). When sulphide-bearing coal with pyrite (FeS_2) is exposed to moisture and oxygen during mining, it results in the formation of AMD. The intensity and duration of AMD are complex functions of geology, mineralogy, hydrology, and the interaction of climatic conditions upon mine waste (White *et al.* 1999). In addition, the rate and degree by which AMD proceeds can be increased by the action of iron oxidizing bacteria, such as *Thiobacillus ferrooxidans* (Singer and Stumm 1970). Development of proper AMD management strategies in mining areas requires fundamental understanding of physiochemical and geological properties, as well as leaching behaviour of geologic formations such as coal beds and surrounding rocks prior to actual mining.

In South Africa, generation of contaminated water from abandoned coal mines remains a major environmental concern. The environmental impacts of AMD have been reported in the Witbank coal mines (Bell *et al.* 2001; Hobbs *et al.* 2008; Mey and van Niekerk 2009; Oberholster *et al.* 2010; McCarthy 2011).

The present work focuses on the characterisation of the potential acid leachate from raw coal, discard coal and slimes in a proposed colliery in the Witbank coalfield, Arnot North coal reserves, by means of geochemical static and kinetic techniques, and mineralogical study.

The coal seams in the Witbank Coalfield were formed in an epicontinental environment and occur within the Vryheid Formation, which forms the mid-part of the Ecca Group (Bell *et al.* 2001). The formation consists primarily of sandstone, siltstone, mudstone and shale, which represent the Ecca Group of the Karoo sequence. The economic coal seams are contained at depths from a few metres to about 300 m in the largely horizontal Ecca Series of the Karoo geological system. Five seams are developed in the Witbank Coalfield (Cairncross *et al.* 1990).

Materials and methods

Three types of representative samples of raw and discard coal, and slimes were studied. Both static and kinetic tests were done on the representative samples based on the procedures set by Sobek *et al.* (1978), APHA (1989), Lepakko (1994), Miller *et al.* (1995). Static tests included; paste pH, Neutralization Potential Analysis, Acid Potential Determination, and kinetic test was by column leaching for a period of 19 weeks. Geochemical composition determination was done using X-ray fluorescence spectrometry, and mineralogical analysis, using X-ray diffraction technique. In addition, sulphur and carbon content of raw and discard coal were determined using LECO induction furnace method.

Results interpretation

Geochemical data

Si_2O and Al_2O_3 were predominant in raw and discard coal, although the latter was also rich in Fe_2O_3 (Table 1). In lesser quantities were TiO_2, K_2O, Na_2O, MgO, MnO, and Cr_2O_3. Discard coal contained significant amounts of As, Cr, Pb, Ni, and Ce which are potential toxic metals, whereas raw coal was enriched in Sr, Ba, Co and Zn (Table 2). Raw coal and slimes contained the highest concentration of carbon (55–62.4 %) and lowest concentration of sulphur (0.3-0.6 %), whereas discard coal had the lowest concentration of carbon (20–29 %) and highest concentration of sulphur (0.6-3.7 %).

Mineralogical Data

Kaolinite ($Al_2Si_2O_5\ (OH)_4$) was the most abundant mineral in raw coal, whereas quartz (SiO_2) was dominant in discard coal. Discard coal contained also pyrite (FeS_2), siderite ($FeCO_3$), mica [$KAl_2\ (Si_3Al)O_{10}(OH, F)_2$], calcite ($CaCO_3$) and gypsum ($CaSO_4.2H_2O$). Pyrite which is a major acid producing mineral (Plumlee 1999) was found to be high and this conforms well to the LECO furnace sulphur content of 4.1 %. Kaolinite, mica and siderite are considered as potential acid neutralizers, but to a much lesser extent compared to carbonate minerals such as calcite (Jambor 2003; Blowes *et al.* 2003).

Acid base accounting

The calculated parameters, such as net neutralization potential (NNP as kg/ton $CaCO_3$), and net potential ratio (NPR) have been used as criteria to classify the acid producing potential of the coal. Paste pH for raw coal was about 6.3 and that of slimes was between 3.5–7.5, whereas discard coal had a pH between 2.2–3.8 (Table 3). A low pH may be indicative of sulphides that have reacted to produce acid, whereas a high paste pH could be indicative of a high concentration of alkaline minerals in coal.

A scatter plot for paste pH *vs.* sulphur content shows that paste pH increases with decreasing concentration of sulphur and vice versa (fig. 1). Based on this, the potential for raw coal and slimes to generate significant acid is low, whereas discard coal has high potential to generate acid. A classification of the samples based on the AP and NP ratio is presented in Fig. 2. Raw coal plotted at NPR<2, hence it is classified as potential non-acid generating, whereas slimes plotted at 1<NPR<1, hence it is classified as both potential acid generating and in uncertain range.

Column leaching results

Considerable amount of acid and sulphate was leached from discard coal than in raw coal and slimes. In discard coal, 6,435 to 8,437 mg $CaCO_3$ of acid was leached per kg of discard coal in the first week of the column leaching test, whereas only 1,125 to 1, 500 mg $CaCO_3$ of acid was leached per kg of raw coal (fig.3). Considerable amount of sulphate load was also leached in

Oxides	*Raw coal wt%*	*Discard coal wt%*
SiO_2	10.49	38.14
TiO_2	0.32	0.94
Al_2O_3	5.14	11.9
Fe_2O_3(t)	0.22	6.8
MnO	0.022	0.04
MgO	0.05	0.16
CaO	0.14	0.59
Na_2O	0.07	0.28
K_2O	0.08	0.21
P_2O_5	0.18	0.04
Cr_2O_3	0.01	0.013
L.O.I.	81.88	39.66
TOTAL	98.61	98.78
H_2O^-	5.39	4.49

Table 1 *Chemical composition of raw coal and discard coal samples (wt %).*

Elements	Raw coal	Discard coal
As	<4	12
Ba	563	245
Br	4.7	101
Ce	56	103
Co	18	12
Cr	42	74
Ga	15	24
Ge	3.4	<1
La	29	51
Mo	<2	3.3
Nb	4	16
Nd	23	37
Ni	24	26
Pb	9	23
Rb	5	13
Sc	6.9	13
Se	<1	2.1
Sr	441	64
Th	4.2	16
U	4.4	3.1
V	40	61
Yb	<2	3.7
Zn	3.80	1.20
Zr	85	179

Table 2 *Trace elements in coal (mg/kg).*

the first week of column leaching test from discard samples (1,400–12,750 mg sulphate/kg), than in raw coal and slimes (175–1,700 mg sulphate/kg) (fig.4). Acid generation and sulphate rate in all samples decreases with time. After nineteen weeks of leaching test, 70 mg $CaCO_3$ of acid and 105 mg sulphate were leached per kg of discard coal, whereas 8 mg $CaCO_3$ of acid and74 mg sulphate leached per kg of raw coal.

Conclusions

In this study mineralogy and bulk geochemical analyses that were undertaken showed a clear variation in chemistry of the samples and this conforms to the likely leachate from the samples as determined by static and kinetic geochemical prediction techniques.

Based on wt % S, NPR, NNP, the raw coal from a colliery in the Witbank coalfield has no potential to generate acid as it contained low sulphur. The column test revealed that raw coal leaches neutral pH over a period of 19 weeks.

	Paste pH	wt% S	NP (as kg $CaCO_3$/t)	AP (as kg $CaCO_3$/t)	NNP (as kg $CaCO_3$/t)	NPR	NAG pH
Raw coal 1	6.28	0.3392	24.3	10.6	13.7	2.3	3.5
Raw coal 2	6.24	0.3488	23.3	10.9	12.4	2.1	3.74
Slimes 1	7.5	0.4	21.4	12.5	8.9	1.7	2.82
Slimes 2	3.51	0.5984	5.9	18.7	-12.8	0.3	1.86
Discard coal 1	3.83	0.5728	15.5	17.9	-2.4	0.9	2.31
Discard coal 2	3.05	3.6992	-4.6	115.6	-120.2	0.0	1.66
Discard coal 3	2.18	1.2992	-15.7	40.6	-56.3	-0.4	2.14
Discard coal 4	2.32	1.4496	-26.1	45.3	-71.4	0.0	1.62

Table 3 *Acid base accounting results for the samples.*

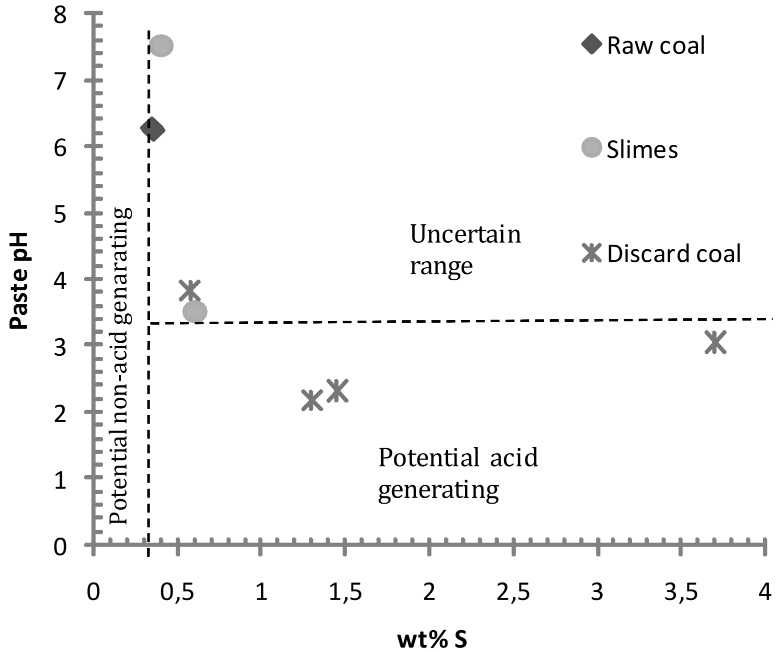

Fig. 1 *Paste pH vswt % S indicating areas of potential acid generating, uncertain range and potential non-acid generating.*

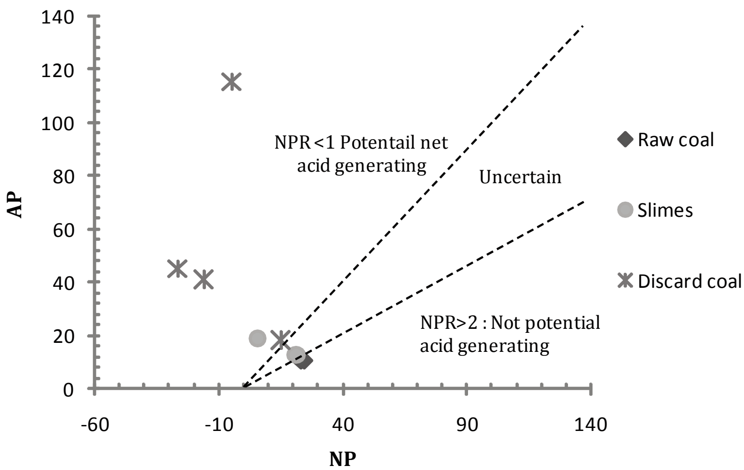

Fig. 2 *Acid potential and Neutralisation potential graph indicating areas of potential acid generating, uncertain range and potential non-acid generating.*

Discard coal was found to be a potential producer of acid upon leaching. X-ray diffraction analysis indicated that discard coal contained about 5 % of pyrite (acid producing mineral), and about 1 % of calcite (buffer mineral). In addition, kinetic test showed that discard coal produced acidic leachate upon leaching that occurred in two phases: the initial rapid acid leachate phase over a period of 1 to 7 days, followed by cyclic buffering due to dissolution of calcite and less reactive silicate minerals, notably kaolinite, mica and siderite.

Recommendations

The study showed that discard coal will produce significant acid leachate, especially during the initial stages of mining. Therefore, the main challenge of the company is to ensure that long-term, environmentally acceptable approaches are put in place to meet the stringent regulatory requirements and public concerns, and to reduce possible environmental contamination that may result from the discard dumps. Consequently, there is a need to carry out further work on the design of discard dumps to ensure minimal acid water generation.

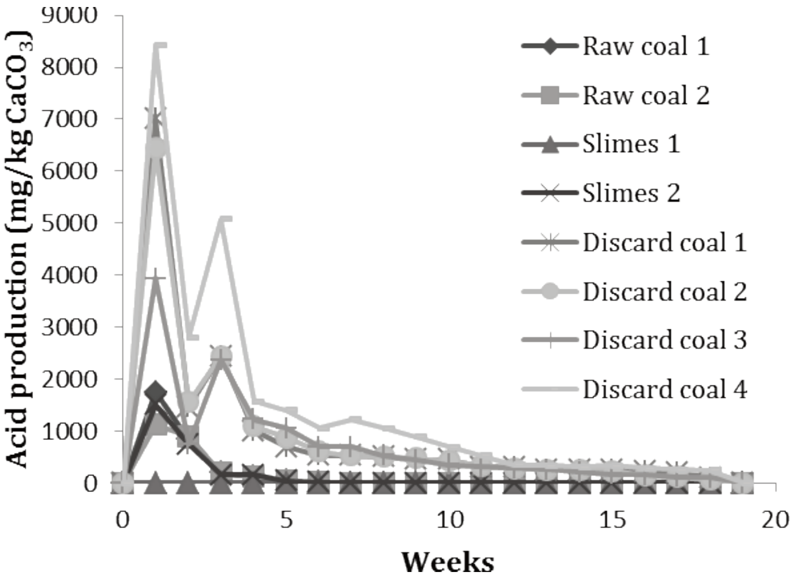

Fig. 3 *Rate of acid generation of samples during phase 2 column leaching test.*

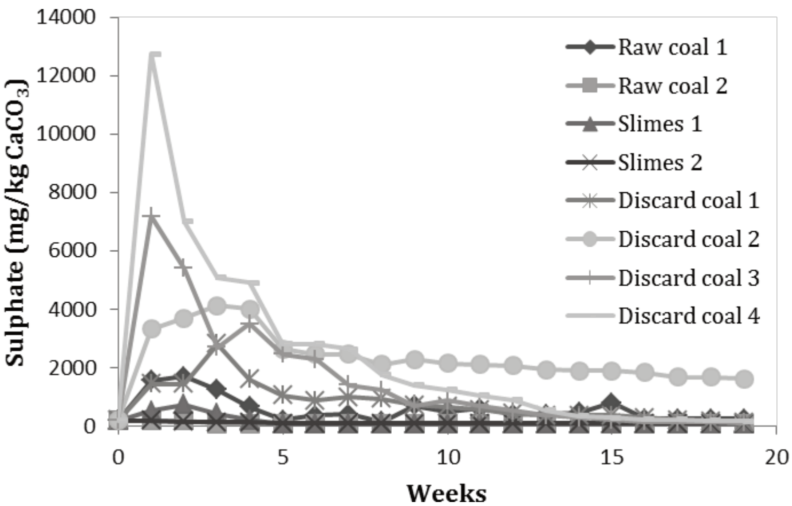

Fig. 4 *Rate of sulphate generation of samples during phase 2 column leaching test.*

Acknowledgements

This work was supported by the THRIP funds at the Council for Scientific and Industrial Research (CSIR) of South Africa, hence much appreciation for funding and the opportunity to conduct the work at the CSIR.

References

ALPHA (1989) Standard method for the examination of water and waste. American Public Health Association, 17 edit., Washington DC, p 44–90.

Arnesen RT, Iversen ER (1997) The Lokken Project – flooding a sulphide ore mine. Proceedings of 4^{th} International Conference on Acid Rock Drainage, Vancouver, BC, Volume III: 1093–1107.

Bell FG, Bullock SET, Halbich TFJ, Lindsay P (2001) Environmental impacts associated with an abandoned mine in the Witbank Coal field, South Africa. International Journal of Coal Geology: 11–25.

Blowes DW, Ptacek CJ, Jamvor LJ, Weisener CG (2003) Geological prediction of metal leaching and acid Generation; geological control and baseline assessment. Geology and ore deposits; the Great Basin and Beyond, Proceedings, Vol. II: 8–20.

Cairncross B, Hart RJ, Willis JP (1990) Geochemistry and sedimentology of the coal seams from the Permian Witbank Coalfield, South Africa; a means of identification. International Journal of Coal Geology, 16: 309–325.

Hobbs P, Oelofse S, Rascher J (2008) Management of environmental impacts from coal mining in the Upper Olifants River Catchment as a function of age and scale. Water Resources Development, 24(3): p 417–431.

Jambor JL (2003) Mine-Waste Mineralogy and Mineralogical Perspectives of Acid-Base Accounting. In: JL, Jambor, DW Blowes and AIM Ritchie (Eds.), Environmental Aspects of Mine Wastes, Short Course Series Vol. 31, Mineralogical Association of Canada, 117–146.

Lepakko K (1994) Evaluation of neutralization potential determinations for metal mine waste and a

proposed alternative. In Intenational Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, PA, USA, US Bureau of Mines Special Publication, SP 06A-94, Vol. 1: 129–137.

McCarthy TS (2011) The impact of acid mine drainage in South Africa.South African Journal of Science, 107(5/6):1 – 7.

MeyWS, van Niekerk AM (2009) Evolution of mine water management in the Highveld coalfields.International Mine Water Conference, 19 – 23 October 2009, Pretoria, South Africa

Miller SD, Jeffery JJ, Murray GSC (1995) Identification and management of acid generating mine wastes; procedures and practices in Southeast Asia and the Pacific Regions. In Gadsby JW, Malick JA, Day SJ (eds.) Acid mine drainage designing for closure, Vancouver, BiTech Publishers Ltd., p 1–11.

Oberholster PJ, Myburgh JG, Ashton PJ, Botha AM (2010). Responses of phytoplankton upon exposure to a mixture of acid mine drainage and high levels of nutrient pollution in Lake Loskop, South Africa, Ecotoxicology and Environmental Safety, 73:326–335

Plumlee (1999)The Environmental Geology of Mineral Deposits. In: G.S. Plumlee and M.J. Logsdon (Eds.), The Environmental Geochemistry of Mineral Deposits, Part A: Processes, Techniques and Health Issues, Reviews in Economic Geology Vol. 6A, Society of Economic Geologists, Inc., 71–116.

Singer PC, Stumm W (1970). Acid Mine Drainage: the rate determining step Science: 167.1121-1123.

Sobek AA, Schuller WA, Freeman JR, Smith RM (1978) Field and laboratory methods applicable to overburdens and mine soil, WVU, EPA report No. 600/02-78-054: 47–50.

White WW, Lapakko KA, Cox RL (1999) Static test methods most commonly used to predict acid mine drainage: practical guidelines for use and interpretation. Society of Economic Geology., vol.7: 325–338.