Prediction of seepage quality from coal discard material in an semi-arid climate

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Abstract

In the prediction of seepage chemistry an important aspect is the upscaling of the results of laboratory scale kinetic test work to equilibrium conditions typical of full-scale mine site components.

Geochemical characterisation was conducted on coal discard waste material as part of a cover design options analysis. Humidity cell results were up-scaled by modelled gravimetric moisture to predict interstitial/pore water TDS concentrations range. The up-scaled seepage quality ranges were evaluated for solubility controls in PHREEQC. The study formed part of an integrated source-pathway-receptor modelling for single and dual-layer store and release covers to mitigate contaminated seepage entering the groundwater.

Keywords: coal discard, humidity cell, source-term, source-pathway-receptor modelling

Introduction

Alternative cover design options with the least potential for groundwater contamination and post-closure risk was investigated in terms of the requirements of the National Environmental Management: Waste Amendment Act - NEMWAA, 2014 (Act No. 26 of 2014) and regulations GN R.634 to 636 for management of mining residues. The investigation involved a source-pathway-receptor (SPR) approach to quantify relationships between the sources of contamination (Discard Dump) and (potential) receptors of contamination by considering relevant pathways and processes. Integration from unsaturated flow modelling, geochemistry and groundwater specialist studies demonstrated the environmental impacts from selected cover designs. The cover design options included a geosynthetic cover and soil cover with varying thickness. Thick soil covers over coal discard facilities in arid and semi-arid regions are considered a cost-effective store and release covers that are cost-effective to mitigate the impacts of acidic to saline seepage entering the receiving groundwater environment.

The paper presents the geochemistry component of the risk-based SPR modelling. The receiving groundwater, of low background quality, was defined as the receptor in the modelling study. The coal mine is situated on the Waterberg coalfield near Lephalale in the Northern Province of South Africa. The regional geology in the area is characterised by the igneous and sedimentary rocks of the Karoo Supergroup, comprising from surface of the Stormberg Group, Beaufort Group, Ecca Group and the Dwyka group forming the basement. The coalfield is fault-bounded and forms a graben structure.

Average summer and winter minimum and maximum temperatures range from 11-40°C and 0-28°C respectively. Mean Annual Potential Evaporation (FAO Penman-Monteith (1992) equivalent) of 1710 mm/yr for the study area exceeds Mean Annual Precipitation (MAP) of 430 mm/yr. Rainfall is highly seasonal with 95% of annual rainfall occurring during the rainy season from October till April. According to INAP (2009), this climate is suitable for a store and release cover.

Approach and Methodology

The methodology followed for the geochemistry assessment is consistent with the series Best Practice Guidelines (BPG) for Water Resource Protection in the South African Mining Industry - G4 Impact Prediction (DWAF 2008) and Global Acid Rock Drainage - GARD Guide (INAP, 2012). The methodology applied included:

Review: Previous discard material static and kinetic characterisation and onsite soil availability reviewed, to develop fieldwork and sampling plan and cover designs options.

Fieldwork and Sampling: In-situ permeabilties (soil and discard material) determined, and fresh and oxidised discard samples collected from test pits (≈ 3.5 m in depth) on ramps and centre of the dump. The samples were submitted for geochemical static and kinetic characterisation to SANAS -accredited laboratories. Static testwork included; minerology by XRD; total elemental analysis by four acid digestion; Acid Base Accounting (ABA); sulphur speciation; Net Acid Generation (NAG); Distilled water leach at 1:20 solid: liquid ratio and analysis of the leachate; Particle size analysis; and humidity cells for kinetic testing; and soil moisture contents.

Geochemical and Unsaturated modelling: Average oxygen consumption in the 50m coal discard dump calculated in 1D Oxygen diffusion model. Modelling of moisture variation within the discard profile as a function of climate, water retention and insitu permeabilities completed in SVFLux software (SoilVision Systems). Modelled moisture time series used to upscale weekly kinetic data to derive interstitial/pore water (seepage) qualities ranges. PHREEQC Interactive (Parkhurst and Appelo, 1999) was used to identify solubility controls on the average, 10^{th} and 90^{th} percentile seepage qualities.

Log triangular distribution of seepage TDS concentration used as input in ConSim model (Golder, 2005) and ChemFlux finite element unsaturated contaminant transport model (SoilVision Systems 2016) to simulate TDS loads at the base of the facility and vadose zone pathway. Monitoring time series data from historic boreholes immediately surrounding the facility was used to validate model results. Unsaturated pathway modelling integration for thick single- and dual-layer store and release covers constructed with onsite soils is presented in Van Zyl et.al (2018).

Impact Assessment: Solute transport model (MODFLOW software) demonstrated the potential risks to the downstream groundwater receptor for cover design options by modelling dispersion, and dilution of TDS loads in surrounding areas from the coal discard dump.

Results

Field programme

Table 1 provides coal discard and interburden samples (27) collected from the mine that report to the coal discard facility.

In-field permeability measurements with a Guelph permeameter were completed on 3 sites on coal discard dump and potential soil cover materials identified onsite. The saturated hydraulic conductivities (Ksat) for the coal discard was measured as 5.90 × 10-3 - 2.52 × 10-2cm/s or 5.0 to 21.5 m/day. The Ksat is very high due to the high coarse fragments (>4.75 mm) contents of ≈63-81%.

Table 1. *Discard Materials Collected (2006- 2016)*

Material Type/Source	Discard Age	Date	Sample ID	No.samples
Discard facility	Partially weathered (1 yr)	2006	Discard_comp	3
Discard facility-NE,	Historic, weathered test pits (≈10 yrs)	2016	Discard_1300, Raffu ramp	2
Northern ramp	Partially weathered-fresh	2007,	Kidney_discard	2
Discard stockpile	(≈2 mon)	2016		8
Wash Plant	Fresh discard	2006	GG1, GG2,GG4,GG5	4
		2016	GG2, GG8, GG1 GG4/5	3
Interburden	Fresh blasted material	2006	Bench 7A,8,10	3
		2007	Bench 7A,8,10	2
		2016	Bench 8&10	

Analytical programme

Characterisation of the discard material involved: moisture content determination; particle size distribution analyses; Acid base accounting (ABA) with sulphur speciation, Mineralogical analyses (XRF and XRD); Distilled water shake flask test and kinetic tests by humidity cell method

Analytical results

Sulphur speciation results for selected samples indicated that sulphide S is the dominant sulphur form in the coal discard materials collected from the Plant and discard facility. Acidic-circum-neutral Paste pH results indicate the presence of dissolving carbonates to buffer acid generation from sulphide minerals in the short-term. Mineralogical compositions for the discard samples indicated calcite ≈1-2%, dolomite ≈1-2% and pyrite ≈1-3%.

ABA results (Figure 2) indicated that majority coal discard sample (with exception of 1 fresh plant discard) have low Nett Potential Ratio or NPR (ratio of Neutralising Potential - NP and Acid Potential - AP) < 2. The coal discard sample classified as Potentially Acid Generation (PAG) according to Price.

Table 2. *Sulphur Speciation for selected coal discard samples*

Sample	Paste pH	Total C	Total S	Sulphide S	Sulphate S	S other
Kidney_discard	7.7	16	1.8	1.6	0.024	0.086
Discard_1300	3.6	13	1.3	0.32	0.50	0.44
Raffu_ramp	5.5	13	1.1	0.28	0.47	0.30
Plant_GG2	7.7	12	2.3	2.1	0.010	0.18
Plant_GG8	7.4	34	3.3	2.9	0.004	0.36
Plant_GG1	7.6	11	2.6	2.5	0.009	0.051
Plant_GG45	6.9	34	6.4	6.4	0.007	0.023
GG1_HC1	na	na	3.4	3.0	0.005	0.45
GG2_HC2	na	na	1.7	1.5	0.013	0.22
GG4/5_HC3	na	na	8.1	6.7	0.013	1.46
Bench 8 –HC4	na	na	6.4	5.2	0.015	1.18
Bench 10-HC5	na	na	0.07	0.02	0.01	0.04

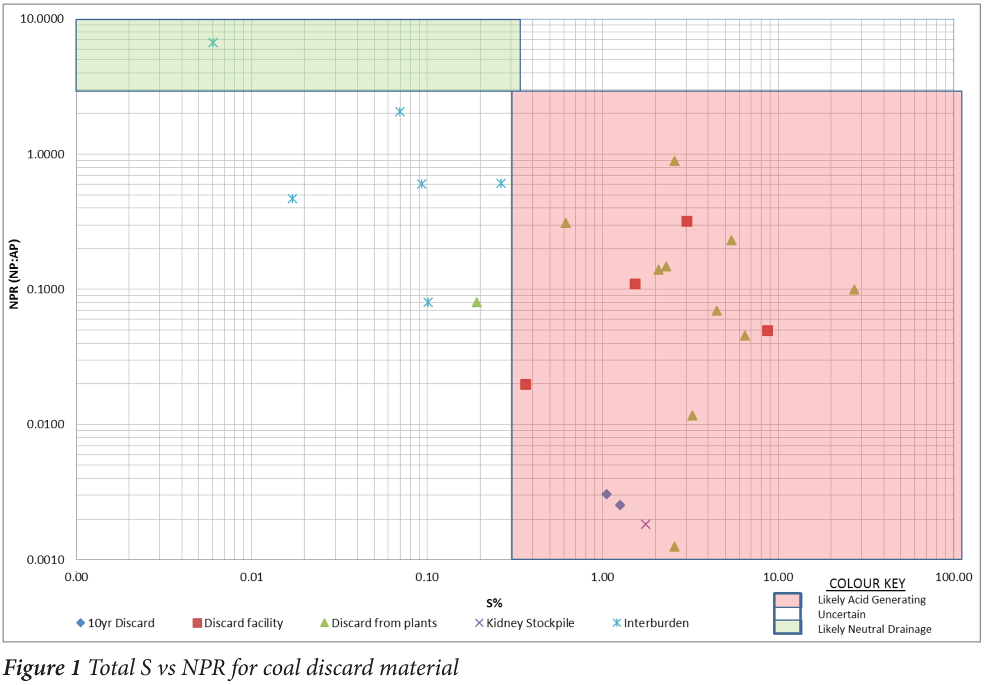

Figure 1 *Total S vs NPR for coal discard material*

Kinetic Results

Selected kinetic results for the coal discard material were assumed representative of coal discard facility. The highest TDS rate (2 700 mg/kg/week) was recorded for Plant 4&5 that handles coal with Tot S > 6%. The results for Plant 4&5 was included since it contributes < 25% of the total volume of discard material reporting to facility. Material balance for discard volumes from each plant was not made available for the study (Figure 2 and 3).

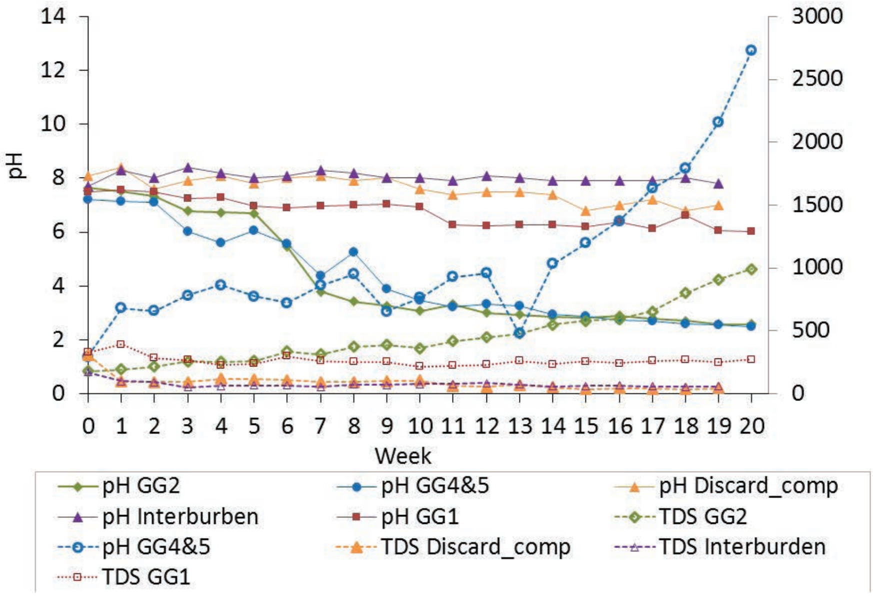

Figure 2: Kinetic results for coal discard material pH and TDS rate vs time

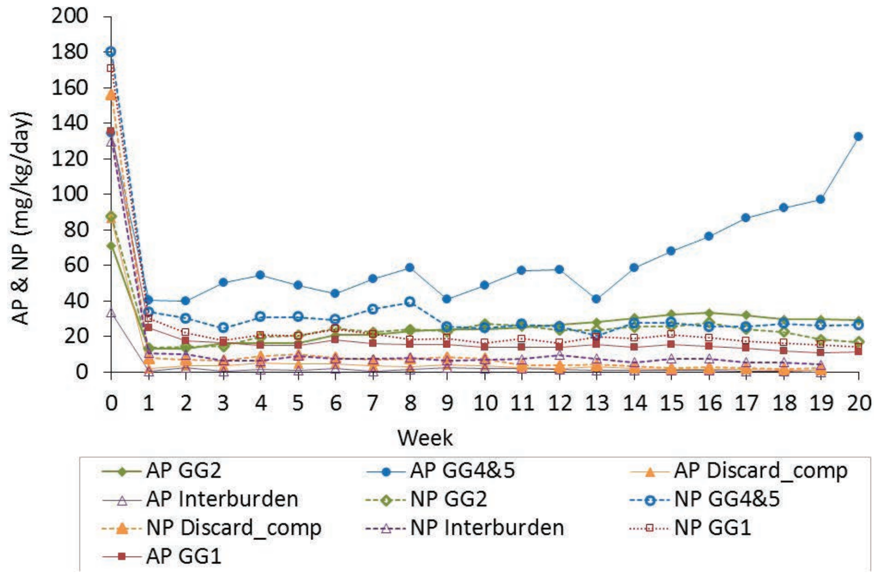

***Figure 3** Kinetic results for coal discard material - Acid Potential and Neutralisation Potential (NP) vs time*

Modelling Results

Oxygen diffusion

Oxygen is a rate-limiting factor in geochemical processes in discard materials. Indicative diffusion rates and oxygen concentrations at depth within the discard materials were calculated Fick's law. Atmospheric oxygen was predicted to be available at depth of the coal discard facility (50m). Table 3 presents the primary oxidation rate from humidity cells and from oxygen diffusion modelling.

Moisture content

One dimensional flow profiles (0-5m and 5-50m) were used to model the moisture conditions and saturation within the coal discard facility. The assumption is made that the simulated moisture and flow through the one dimensional flow profiles are spatially representative of the flows that would occur at the various sections. The predicted distribution in gravimetric water/moisture content or for an uncovered discard is shown in Figure 4. The moisture contents (Table 4) was predicted from precipitation, rainfall distribution and climate conditions, material hydraulic properties of three (3) discard samples and the effect of moisture retention of the discard profile.

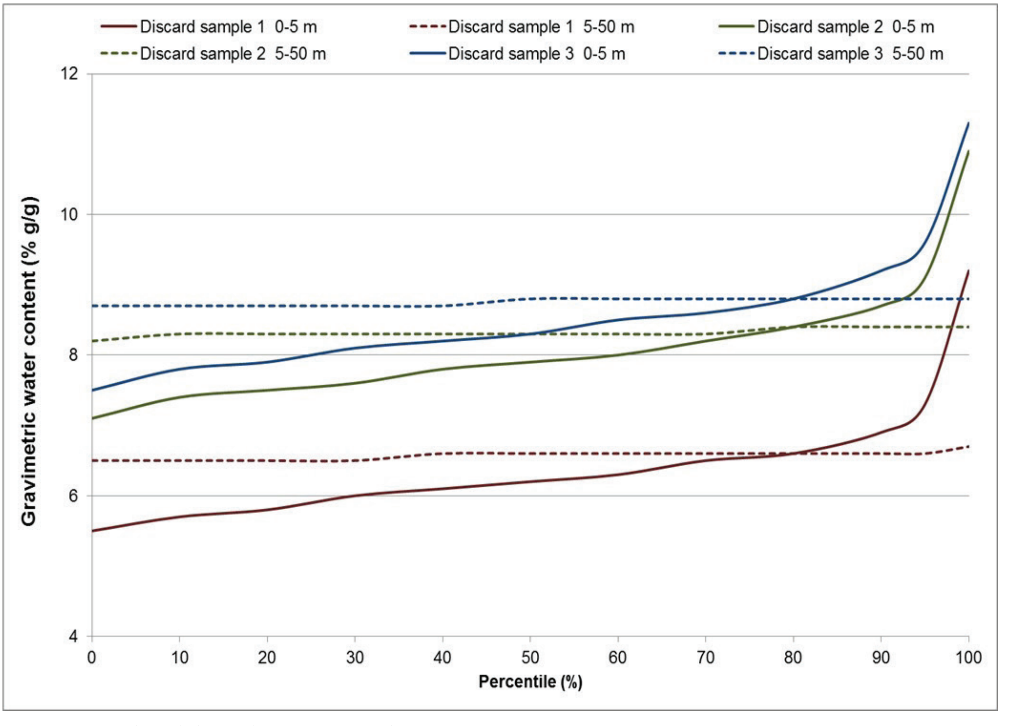

Figure 4. *Predicted discard moisture conditions*

Table 3. *Predicted oxygen diffusion rates*

Primary Oxidation Rates				
	Units	Min	Ave	Max
Oxygen flux at waste interface	$KgO_2/m^2/s$	1.78E-08	2.50E-08	3.00E-08
Calculated pyrite oxidation rate	$gFeS_2/t/week$	1.2	1.6	2.0
Humidity cell rates for pyrite oxidation	$gFeS_2/t/week$	215	428	313
Number of times slower than humidity cell rates		185	261	313

Table 4. *Moisture Modelling Results*

	Discard 1	Discard 2	Discard 3
Laboratory measurements	5.7	7.4	7.8
Predicted moisture	6.5	7.5	8.9

The modelled moisture content time series was applied to upscale weekly humidity cell (liquid: solid ratio of 2:1) results as representative of coal discard interstitial pore solution over time. Geochemical solubility controls were assessed on the 10th, average and 90th percentile up-scaled pore qualities for each humidity cell in PHREEQC Interactive (USGS, 2017).

Table 5 provides the predicted seepage quality (selected parameters) from the coal discard facility under oxidising conditions and in equilibrium with air (O_2 and CO_2). Selection of pyrite as an equilibrium phase switches the redox to slightly reducing conditions. The elevated magnesium and sulphate concentrations is due to pyrite oxidation; and subsequent dolomite buffering. Minerals predicted to control the dissolved concentrations (sulphate, calcium, chromium, manganese, iron, aluminium and barium) in the seepage were; gypsum, $Cr(OH)_3$(am), rhodochrosite, goethite, diaspore, and barite and dolomite.

A log-triangular distribution for TDS seepage from the coal discard (Table 5) was applied in the ConSim model for various cover options to simulate flow to the unsaturated zone and immediate groundwater environment (after dilution into the receiving groundwater).

Table 5. *Summary of PHREEQC modelling (selected parameters) for coal discard seepage*

Parameter	90th Percentile	Average	10th Percentile
pH	4.59	7.83	8.02
pE*	0.3-11	-3.6-8.0	-3.9-8.0
Alkalinity	<1	47	59
Cl	21	10	2.2
S(6)	8 292	2 535	342
TDS (by Sum)	10 781	3 387	517
F	5.5	2.8	0.27
Na	53	30	6.0
K	67	34	6.2
Ca	446	541	111
Mg	1 691	191	18
Al	4.6	0.00035	0.00048
Fe	152	0.12	0.028
Mn	24	2.1	0.20
Cr	0.0080	0.00023	0.00014
Cu	0.068	0.067	0.0033
Si	14	6.9	0.17
Zn	15	0.44	0.15

Conclusions

Lower moisture retention and saturation predicted in the uncovered discard material resulted poor seepage quality due to high rate of oxygen diffusion and higher oxidation rates. Source-pathway-receptor modelling, based on site specific conditions and cover configurations demonstrated potential long-term impacts from a thick evaporative covers and geosynthetic liner. The overall study approach demonstrated that the required groundwater quality criteria can be met with the alternative (cost-effective) cover design.

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