Determination of acid rock drainage from underground coal gasification at a pilot plant in Majuba

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Abstract

Underground coal gasification is an unconventional mining method that gasifies coal in situ to produce a synthetic gas that can be used for electricity generation. Residue products from underground coal gasification (UCG) have the potential to leach into groundwater. The products include char, ash and the surrounding in-situ rocks. The acid generation capacity of these products are explored in this study using acid base accounting (ABA). ABA results that the gasification zone in UCG operations will be a mixture of acid producing and acid neutralizing species, hence it is possible that the overall conditions might be neutral to weakly acidic as seen in the final pH.

Keywords: Acid base accounting | Underground coal gasification | Acid rock drainage

Introduction

Underground coal gasification (UCG) is an unconventional mining method that converts coal into gas by in-situ gasification. This process uses a panel of injection and production wells that are drilled to the coal seam to achieve gasification and transportation of the gas to the surface. Oxidants in the form of a mixture of oxygen and steam are injected into the gasification zone via injection wells and take part in UCG reactions. The gasification process converts solid coal into gaseous phases composed mainly of methane, hydrogen, and carbon monoxide known collectively as synthetic gas. The synthetic gas escapes through production wells to the surface where a number of gas scrubbing plants are installed to achieve the desired subsequent gas that can be used for electricity production. The mass transfer of solid coal to gaseous phases leaves a void or cavity in the coal seam which gets partly filled with residue products, ash and char (Figure 1).

Underground coal gasification has less environmental impact than conventional coal mining as most of the waste handling and

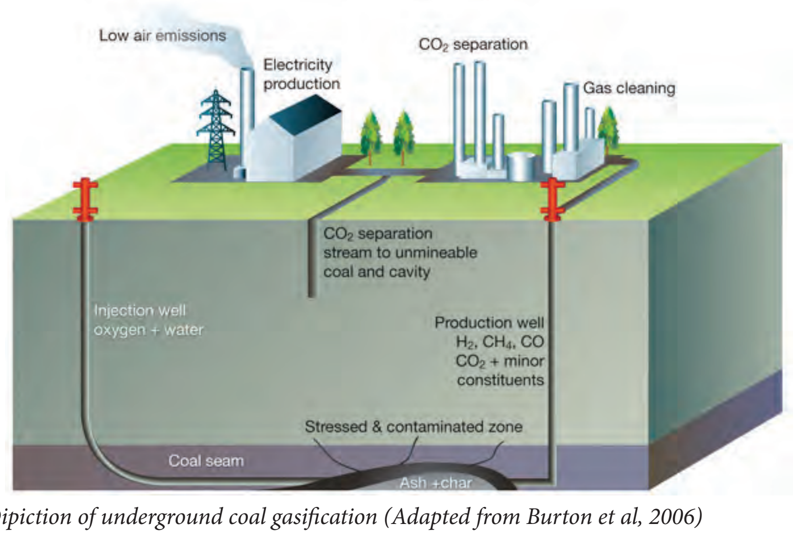

Figure 1 *Dipiction of underground coal gasification (Adapted from Burton et al, 2006)*

coal processing is eliminated (Imran et al., 2014). In traditional coal mining techniques, coal is mined and transported to the point of use where it is stockpiled before processing. All this processes have negative impact on the environment such as groundwater contamination, subsidence, surface disturbance and atmospheric pollution. At the tail end of the coal value chain is the waste handling of ash which also add to the environmental risk and cost. UCG technology has advantages that include improved health and safety of mining, reduction in coal processing and waste handling and less surface damage from mining activity. Carbon capture and sequestration technology can be incorporated into UCG by utilizing the cavity as a Carbon dioxide storage chamber hence further reducing the environmental effects from UCG activities (Bhutto et al., 2013).

Underground coal gasification offers a number of environmental solutions to coal exploitation, however groundwater contamination remains the main environmental risk (Kapusta and Stańczyk, 2011). Reports of groundwater pollution have been documented from the UCG test site in Hoe Creek, where product gas comprising of phenols and condensed vapours penetrated the overlying hydraulic units due to high pressures in the UCG reactor (Imran et al., 2014). Contaminants can migrate and penetrate the surrounding rocks as a result of an outward pressure from the gasification zone. It is widely accepted that operating the gasification zone at a pressure lower than the hydrostatic pressure in the immediate aquifer will cause all groundwater movement towards the gasification zone (Imran et al., 2014). This ensures that no outward pressure is exerted in the aquifer and hence containing the organic products within the gasification zone where there is constant decomposition and removal via the production wells. Most of the inorganic contaminants remain in the cavity as ash and char (Liu et al., 2007). These residue products interact with groundwater after the gasifier shutdown when natural groundwater head rebounds and water starts to fill the cavity. The natural flow of groundwater will leach the residue products leading to groundwater pollution (Bhutto et al., 2013).

Study area

The Eskom underground coal gasification pilot plant near Majuba Power Station in Mpumalanga, South Africa, is the first UCG plant in Africa and has already produced synthetic gas and successfully co-fired around 6-MW into Majuba Power Station by 2010. Gasification has ceased and five verification boreholes were drilled into the gasification zone. The aim of the verification drilling was to determine the impact of gasification and hence the boreholes were sited at strategic locations within the gasification panel. Five boreholes were drilled with two off-cavity and three targeted within the gasification zone. The location of the verification boreholes is shown in Figure 1.

The topography of the area is characterized by regular hills attributed to the erosion of the underlying dolerite sill. Four different intrusive dolerite rocks (T1 to T4) that intersect the Karoo sediments in the Majuba Colliery have been identified (de Oliveira and Cawthorn, 1999). The dolerites intrusions have been found to have displaced the targeted Gus seam by over 70 meters in some places. This has led to limitations in effective extraction of the coal seam by conventional mining. The targeted coal seam is the Gus seam that forms part of the Vryheid Formation of the Ecca Group in the Karoo Supergroup. The Gus seam varies from 1.8 to 4.5 m in thickness and in the Majuba UCG site it is encountered at a depth of around 280 m. The coal zone has also been found to bear several thin (5 – 20cm) laterally impersistent bright coal layers below the Gus seam (de Oliveira and Cawthorn, 1999). There are three other identified coal seam above the Gus seam, namely Eland, Fritz and Alfred seams. These coal seams act as marker seam in the Majuba UCG site and are not targeted for gasification. The location of verification boreholes G1VTH1, G1VH2, G1VH3, G1VH4 and G1VH6 are displayed in Figure 2.

Methods

The residue products of UCG will interact with groundwater after the shutdown of the gasifier and the interfaces in the cavity have the potential for acid rock drainage (ARD) especially if the sulphide quantities are ade-

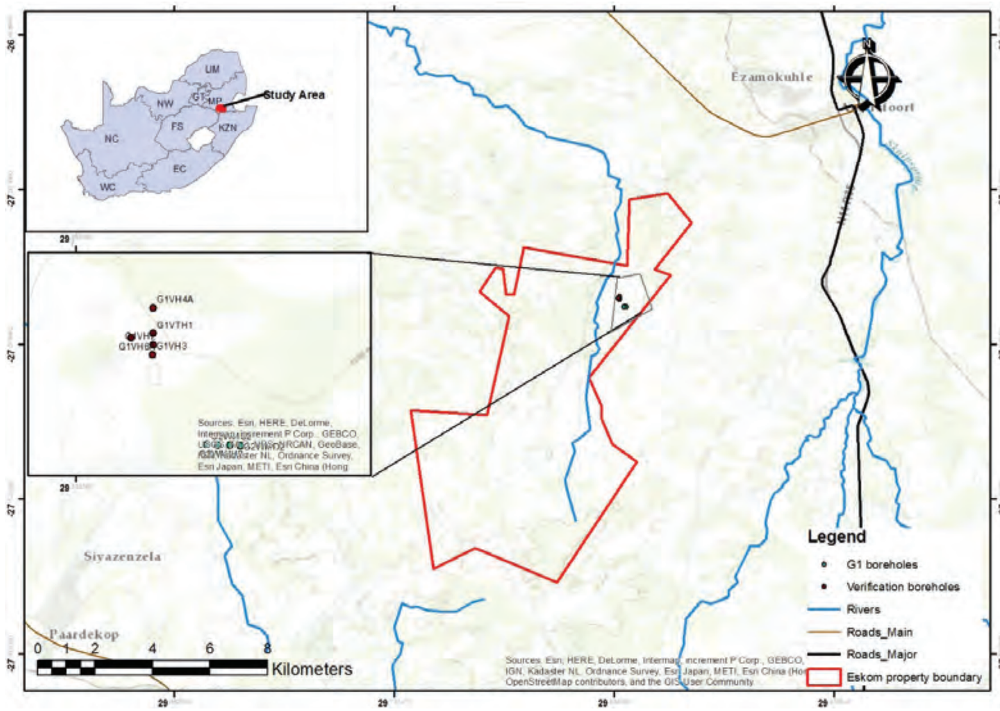

Figure 2 Aerial view of the Majuba UCG site showing the location of groundwater monitoring boreholes with the verification boreholes encircled in red

quate for acid generation. The reaction below shows the oxidation of pyrite which leads to acid generation:

2FeS2(s) + 7O2(g) + 2H2O(l) = 2Fe2+(aq) + 4SO42−(aq) + 4H+(aq) [1]

The reaction produces ferrous iron, sulphate ions and acid. While oxidation of sulphide minerals contribute to the acidity of rock drainage, dissolution of carbonate minerals play a role in neutralizing the acid from the following reaction:

CaCo3(s) + H+(aq) = 3HCO-(aq) + Ca2+(aq) [2]

There are two types of laboratory test that can be used for the prediction of acid rock drainage, static and kinetic tests. Static tests like acid base accounting (ABA) and Net Acid Generation(NAG), are relatively simple to carry out while the kinetic tests usually take longer periods to complete. Due to the limitation in sample size only one method (ABA) could be used in this study. Acid base accounting are described by Sobek et al. (1978) as predictive tool that accounts for the balance between the acid producing potential (AP) and the neutralising potential (NP) of geological material and the difference is calculated as the net neutralising potential (NNP). The acid producing material is generally the sulphide minerals as seen in Eq (1), while the acid neutralising minerals are carbonate minerals such as calcite, dolomite and magnesite, Eq 2.

NNP = NP – AP

The AP is based on the theoretical oxidation of all sulphur in the sample to sulphuric acid. The total sulphur in the samples was determined using a LECO (Laboratory Equipment Corporation of St. Joseph, Michigan) sulphur analyser. AP is generally expressed in kg $CaCO_3$ per tonne of material, the conversion factor is 31.25 kg CaCO3/tonne:

AP = Sulphur content (%) * 31.25Kg CaCO3 per tonne

The dissolution of acid neutralizing minerals such as carbonates contribute towards the neutralization potential (NP). Hydrochloric acid is used to sufficiently digest these minerals and it is expressed in Kg CaCO3 per tonne but can also be converted into Acid Neutralising Capacity (ANC, expressed as kg H2SO4/tonne) by multiplying the NP with 0.98.

The Eskom Majuba UCG pilot plant was successfully commissioned at Majuba coalfield in January 2007 with product gas being co-fired into the nearby Majuba Power station by October 2010 and was successfully operated through to September 2011 when decommissioning commenced with the shutdown of the gasifier (G1). The successful performance and shutdown of the Majuba UCG pilot plant is a significant step towards full commercialization of UCG technology as this is the first UCG plant in Africa. The successful shutdown of G1 presents an opportunity to investigate some of the key environmental questions regarding groundwater contamination. The project has successfully embarked on a drilling exercise to recover residue samples from the gasification zone through what is termed verification drilling. Verification drilling is diamond core drilling from surface to the gasification zone with the aim of retrieving core samples. The successful recovery of ash, char and heat-affected strata provides key insights into the geochemistry of the gasification chamber as these products are regarded as potential sources of groundwater contamination. Samples were taken from the roof and floor of four verification boreholes including the ash and unburned coal.

Results

The ABA results are shown in Figure 3.

The ABA results of show a mixture of acid producing species and also acid neutralizing species. There is one outlier, a sample with a high net neutralization potential of 141.7 kg $CaCO_{3.}$ This inconsistency will have to be investigated by repeating the analysis in order to eliminate possibility of equipment failure or human error. The majority of the samples plot in the uncertainty region of +20 to -20 NNP and will be processed further with kinetic tests to determine their acid potential. In general the results show that the gasification zone in UCG operations will be a mixture of acid producing and acid neutralizing species, hence it is possible that the overall conditions might be neutral to weakly acidic as seen in the final pH.

Conclusion

The ABA results show a mixture of acid producing and acid neutralizing species. Since groundwater will be the leaching medium for the residue products of UCG therefore considerably the leaching behaviour will depend on the chemistry of the local groundwater.

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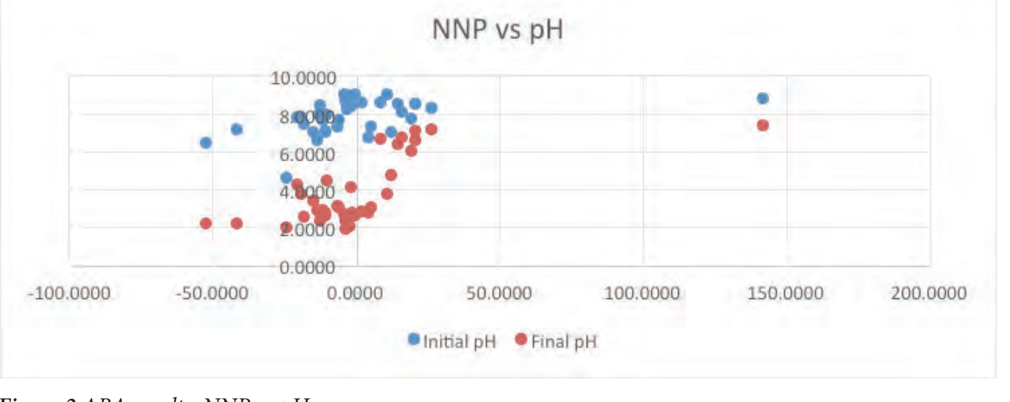

Figure 3 *ABA results, NNP vs pH*

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