WATER RESEARCH 47 (2013) 1021–1034

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Chemical variability of groundwater samples collected from a coal seam gas exploration well, Maramarua, New Zealand

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ARTICLE INFO

Article history:
Received 4 May 2012
Received in revised form
1 November 2012
Accepted 1 November 2012
Available online 8 November 2012

Keywords:
Coal seam gas (CSG)
Coalbed methane (CBM)
Groundwater
Waikato
Hydrochemistry
Geochemical modelling

ABSTRACT

A pilot study has produced 31 groundwater samples from a coal seam gas (CSG) exploration well located in Maramarua, New Zealand. This paper describes sources of CSG water chemistry variations, and makes sampling and analytical recommendations to minimize these variations. The hydrochemical character of these samples is studied using factor analysis, geochemical modelling, and a sparging experiment. Factor analysis unveils carbon dioxide (CO_2) degassing as the principal cause of sample variation (about 33%). Geochemical modelling corroborates these results and identifies minor precipitation of carbonate minerals with degassing. The sparging experiment confirms the effect of CO_2 degassing by showing a steady rise in pH while maintaining constant alkalinity. Factor analysis correlates variations in the major ion composition (about 17%) to changes in the pumping regime and to aquifer chemistry variations due to cation exchange reactions with argillaceous minerals. An effective CSG water sampling program can be put into practice by measuring pH at the wellhead and alkalinity at the laboratory; these data can later be used to calculate the carbonate speciation at the time the sample was collected. In addition, TDS variations can be reduced considerably if a correct drying temperature of 180 °C is consistently implemented.

1. Introduction

Coal Seam Gas (CSG) constitutes an emerging source of natural gas currently under exploration and development in countries like the US and Australia. Similarly, CSG exploration has been taking place in New Zealand with trial production pods in Huntly, Taranaki, and Kaitangata (CRL Energy Ltd, 2010). Although in both Australia and New Zealand CSG exploration and development has been taking place at a considerable pace, there is concern about potential environmental problems that could arise as a consequence of these operations (Taulis, 2010).

CSG is mainly methane gas stored in underground coal seams saturated with groundwater. The methane gas is adsorbed within the micropore structure of the coals held in by potentiometric pressure. To extract this gas, producers depressurize the coal seams by extracting large amounts of water (typically around 40 m^3/day but sometimes up to 100 m^3/day). Therefore, water production is critical for the success of CSG operations. In addition, CSG water chemistry is important as an exploration tool and to assess potential environmental implications arising from disposal issues.

The geochemical signature of CSG waters has been defined by Van Voast (2003) by analysing the CSG hydrochemistry for

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http://dx.doi.org/10.1016/j.watres.2012.11.003

different producing basins in the US. The signature consists of high sodium and bicarbonate concentrations with low calcium and magnesium, and almost nil sulphate. In addition, high chloride concentrations are possible, and particularly in coal beds that are intimately associated with marine beds. In general, CSG waters have high alkalinity with circumneutral pH and their salinity tends to be in the brackish range ($2000 < \mathrm{TDS} < 10{,}000$ mg/L).

A few studies have investigated the hydrochemical nature of CSG waters. For example, Bartos and Ogle (2002) sampled springs, aquifers and CSG wells completed in coal seam aquifers within the Wyodak–Anderson coal zone to characterize recharge and groundwater flow processes within the Powder River Basin (PRB). McBeth et al. (2003a,b) studied the water chemistry and trace element concentrations in discharge points and holding ponds in three Wyoming watersheds. Rice (2003) studied the chemical and isotopic composition of CSG waters sampled from 3 producing fields targeting the Ferron Sandstone in Utah and noted hydrochemical differences which she attributed to separate recharge areas, differences in flow paths, and various solute sources. Patz et al. (2006, 2004) examined the interaction of CSG discharge water with semi-arid ephemeral stream channels. This was done by sampling three discharge wells and seven sampling sites within the stream. Similarly, Jackson and Reddy (2007a,b) collected CSG water samples from outfalls and discharge ponds from five different Wyoming watersheds, and carried out a geochemical analysis to assess salinity and sodicity implications. In addition, Jackson and Reddy (2007a) used a multi-factor Analysis of Variance to analyse CSG water samples in order to identify differences in physico-chemical properties and ion concentrations between watersheds and years, but did not conduct a multivariate Factor Analysis to identify combinations of variables that control variability. In Australia, Golding et al. (2010) studied the hydrochemistry and isotopic composition of CSG waters from Permian coal beds within the Bowen Basin in Queensland; this enabled them to infer the origin of the water based on the proximity to recharge areas while considering the effect of folding and faulting. While in all of these studies the hydrochemistry of CSG waters fits the geochemical signature as described by Van Voast (2003), none of these focus on understanding the transient variations of samples taken from a single well over time.

Decker (1987) presented the hydrochemistry of 30 CSG water samples from a well completed in East Divide Creek Unit, Piceance Basin, Colorado collected between 1985 and 1987. These samples fit the geochemical signature of CSG waters but also exhibit noteworthy hydrochemical variations over time. Decker (1987) studied these variations using Piper diagrams, and inferred that they were caused by a combination of true composition changes and random errors (e.g. sampling and analysis).

The Maramarua coalfield is located in the north-eastern part of the Waikato Coal Region, in New Zealand's North Island. This region is renowned for holding important coal resources within the Waikato Coal Measures. Since 2003, significant CSG exploration activity has been undertaken in this region by both the L&M Group and Solid Energy. In 2004, a CSG exploration borehole (C1) in Maramarua was converted into a CSG pilot test by L&M, and active pumping from this well resulted in 31 CSG water samples. A preliminary analysis of these samples was presented by Taulis and Milke (2007) but no conclusions as to the nature of hydrochemical variations were presented in that work. Therefore, the aim of this article is to unveil the nature of CSG water sample variations from the Maramarua C1 well and to explore the potential implications this could have on co-produced water sampling and characterization.

2. Materials and methods

2.1. *Study area and CSG exploration*

The Maramarua coalfield is bounded by the Maungaroa Fault to the West and by a series of NE trending normal faults separating it into sectors (Mangatangi, Puketoka, Kopuku, Clifton, and Maby sectors) (Edbrooke, 1981). The main coal resources are contained within the Waikato Coal Measures (WCM), deposited in the Eocene, and consisting of carbonaceous mudstones (clay and shales), sandstone conglomerates, fresh limestone, and sub-bituminous coals. The WCM (0–240 m deep) forms the basement part of the Te Kuiti Group (180–600 mm thick) which includes estuarine and shallow marine deposits overlying the WCM (Hall et al., 2006). In August 2003, exploration bore C1 was drilled in the Kupakupa seam within the Clifton Sector (Fig. 1). In June 2004, exploration hole C1 was fitted with steel casing to carry out the pilot gas test. The casing was set with grout to about 2 m above the Kupakupa coal seam to isolate it from overlying units (L&M Coal Seam Gas Ltd, 2005) but no screen or gravel pack were fitted at the open interval.

Between August and October 2004 pilot testing of the Maramarua C1 borehole produced 22 CSG water samples that were analysed at the EEL (Environmental Engineering Laboratory, University of Canterbury). In this particular operation, a "sucker rod" pump was used to pump CSG water to the surface in order to depressurize the Kupakupa seam. Pumping took place continuously except for a few interruptions due to pump break downs. Water samples were collected whenever pumping was resumed and had been ongoing for some period of time. Whenever there was a pump break down, the water level could remain stagnant inside the well for up to several days; the water level would then slowly rise inside the well (due to artesian pressure), but it would decrease as soon as the pump was repaired and depressurization operations were resumed. However, pumping operations were suspended in November 2004 due to ongoing pump problems. Pump testing was resumed in April 2005 when a Progressive Cavity pump was installed in C1 and, between April and June 2005, 9 more samples were collected using this pump.

2.2. *Sampling and analysis*

Common standards for sampling wells usually involve purging the well and taking the sample only after removing about 3 well volumes of stagnant water. In the case of C1, the well was purged continuously throughout the gas test because the aim of the test was to lower the water level (to a level just