Hydrochemical compatibility assessments of aquifer injection of treated coal seam gas water into Surat Basin aquifers.

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Abstract

Aquifer injection is being identified as an option for the management of coal seam gas (CSG) water in Queensland. The feasibility of aquifer injection will depend on a number of issues, including the ability to manage any potential risks to the environmental, economic and social values of the receiving aquifers. A hydrogeochemical assessment to assess the compatibility of re - injection of pure reverse osmosis (RO) permeate and RO permeate / CSG water blends into different target aquifers forms part of the approvals process.

Keywords: CSG, Surat Basin, hydrochemical compatibility, aquifer injection

Introduction

Management of coal seam gas (CSG) water is one of the greatest challenges facing the rapidly developing CSG industry in Queensland, Australia. The demand from regulatory bodies for beneficial use of CSG water, and regulatory disapproval of the traditional method of disposal through evaporation, has increased the need for cost effective, sustainable management options. The feasibility of aquifer injection of treated CSG water into the Great Artesian Basin (GAB) is being investigated as a sustainable management option by the Australia Pacific LNG Project under strict Government guidelines. This paper outlines the process of hydrochemical compatibility assessments undertaken as part of these feasibility studies.

Methods

Trial injection development sites were selected based on infrastructure location, presence of suitable aquifers and aquifer usage. The injection targets at the various development sites included the Hutton Sandstone, the Gubberamunda Sandstone and the Precipice Sandstone, all members of the Surat Basin of the GAB. For these units, monitoring bores that were installed in the target aquifers have provided core and groundwater samples, from which key hydrogeochemical data has been collected.

Monitoring bores were developed using a downhole electrosubmersible pump until water quality parameters had stabilised and a minimum of three bore volumes had been removed, after which water samples were collected. The different target aquifer groundwater qualities from the various development sites, as well as reverse osmosis (RO) permeate and raw CSG waters were analysed for a number of chemical constituents by a inductively coupled plasma mass spectrometer (ICP – MS) (Table 1). Mineralogical analysis by X-ray diffraction (XRD) and scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS), as well as porosity and bulk density was conducted on the core samples obtained from drilling. Handheld X-ray fluorescence (XRF) analysis was conducted using a Niton XL3t GOLDD+ instrument. This analysis was conducted for rapid detection of metals.

Table 1. *Groundwater hydrochemistry parameters.*

Parameter	**Constituents for Analysis**
Major Ions	Ca, Mg, K, Na, Cl, SO_4, Alkalinity
Minor Ions	Br, F, I
Physico-chemical	pH, Conductivity, TDS and TSS
Dissolved Metals and Metalloids	Al, B, Ba, Co, Fe, Mn, Mo, Se, Ag, Sr, Sn, As, Cd, Cr, Cu, Ni, Zn, Si, Hg, Pb
Nutrients	NO_3, NO_2,Total P, Sulphide (S^{2-}) and Dissolved Organic Carbon
CH_4	Dissolved Methane
PAH's	Phenols and Polycyclic Aromatic hydrocarbons
TPH	Total Petroleum Hydrocarbons
TRH	Total Recoverable Hydrocarbons
BTEXN	Benzene, Toluene, Ethylbenzene, Xylene, Naphthalene

The injection assessments were conducted with the aid of PHREEQC (Parkhurst and Appelo, 1999) and Geochemist's Workbench (GWB) (Bethke and Yeakel, 2009). PHREEQC modelling was used for simulating the mixing of different fractions of RO permeate with raw CSG water (50:50 [A], 70:30 [B], 30:70 [C] and a blend that produces a total dissolved solid (TDS) concentration that most closely, but does not exceed, the TDS of the target aquifer [D]) and the injection of these 'blends' into the receiving aquifer (Gubberamunda Sandstone at development site X). GWB was used for simplified 1-D reactive-transport modelling, based on the results of site-specific numerical groundwater flow models of injection (not shown). To date, investigations have been undertaken at four different sites; however, only one site and injection target (development site X; Gubberamunda Sandstone) is discussed in this paper.

Results and Discussion

Mineralogy

The Gubberamunda Sandstone core samples (at development site X) were composed mostly of quartz with subordinate plagioclase, K-feldspar, kaolin and illite/ mica. One of the cores was very differnt because it was dominated by calcite and contained some siderite. The major calcite constituent corresponds to a greater bulk density and considerably lower porosity; likely due to calcite cementation, which was observed in the core. The hand-held XRF results show variability in concentrations of major elements such as Si, Ca, Fe and Al, which reflects the mineralogy of the cores. In addition, the analyses detected the presence of trace quantities of several metals (e.g. Cr, Mn, V, Pb and Zn) that may have implications for water quality post-injection should these elements become mobile as a result of the injection of permeate or blends into the aquifer. It is noted that no arsenic was detected in any of the samples; however, sulphur was detected by handheld XRF with an average of 0.15 mg/kg. Although pyrite (FeS_2) was not detected in the Gubberamunda Sandstone (at development site X), it was observed and recorded in the Precipice Sandstone for another injection target with SEM-EDS. Pyrite was therefore included in the geochemical models as a conservative assumption for the simulations.

Hydrochemistry

The Gubberamunda Sandstone groundwater (at development site X) has moderate salinity (TDS in the order of 845 mg/ L) and a slightly alkaline to neutral pH (pH ~ 8.5) (Table 2). The groundwater was mostly composed of Na and HCO_3 with subordinate Cl, CO_3, SiO_2, Ca and K. The RO permeate (from development site X) also has a neutral to slightly basic pH (pH= 7.92), and a very low TDS at 76mg/L. The waters is composed mostly of Na and Cl, with the other chemical constituents being measured to be quite low. The raw CSG water at development site X is saline, with a measured EC of 5990 µS/cm and an average TDS of 2590 mg / L. The pH was measured to be slightly basic (average pH = 9.23). The CSG water was dominated by Na and Cl with subordinate F, K, Ca, SO_4 and Br.

Modelling

Based on the PHREEQC Gubberamunda Sandstone aquifer water saturation index (SI) values, the likely water quality controlling minerals (i.e. equilibrium minerals) are Ca - montmorillonite, K-feldspar, illite, K - mica, calcite, chlorite and siderite. PHREEQC was also utilised for simulating the effects of mixing different fractions of RO permeate and raw CSG water. The simulations calculated blend pH values that were slightly basic (pH ~ 9.3), with saline water quality (EC = 1450 – 4200 uS/ cm). With increasing proportions of RO permeate blended; there is a considerable decrease in salinity (i.e. EC value) and Na concentration, which corresponds to a lower calculated sodium absorption ratio (SAR). The increasing EC value may negate the effects of a high SAR value; therefore lowering the impacts of sodicity and reducing clay dispersion. The copper and aluminium concentrations of some of the blends (50:50 and 30:70; RO permeate: CSG water) are elevated, reflecting the impact of the CSG water input. The model simulations for the injection of the different blends into the Gubberamunda Sandstone groundwater (at development site X) were conducted in the presence of the minerals determined to be in control of receiving aquifers hydrochemistry (i.e. equilibrium phases) (Table 3). The simulations indicated slightly basic (pH ~ 9) water quality with moderate salinity (EC ~1500 µS / cm). The resulting water quality is dominated by Na and Cl, with subordinate Br, K, F and SO_4. A significantly high SAR was calculated due to the high Na concentration, together with low Mg and Ca content. The parameters that were simulated in the models (excluding pH), meets all Australian drinking water guidelines (NHMRC, 2011) and the Australian and New Zealand Environment and Conservation Council (ANZECC) Guidelines (95% species protection level) (ANZECC, 2000). The predicted pH was only slightly above these guidelines.

There is a reduced probability of clay mineral alteration (i.e. clay swelling) when the injectate EC and SAR closely match that of the injection target water; however, as shown in some of the model simulation results, this may cause exceedences for other parameters if CSG water is used to provide less RO permeate -dominated injectate.

Table 2. *Hydrochemistry results for the Gubberamunda Sandstone aquifer, RO permate and raw CSG water at development site X.*

Chemical Name	**Units**	**Gubberamunda Sandstone**	**RO permeate**	**Raw CSG water**
pH (Lab)	pH Units	8.45	7.92	9.23
EC	µS/cm		250.2	5989
SAR*		51.74	105	186
Alkalinity (total) as CaCO3	mg/L	702		2568
Chloride	mg/L	83	47.18	551
Mercury (dissolved)	mg/L	<0.0001	<0.0001	<0.0001
Aluminum (dissolved)	mg/L	0.02	0.026	0.2
Arsenic (dissolved)	mg/L	0.005	< 0000.1	0.003
Barium (dissolved)	mg/L	0.032	0.01	0.62
Boron (dissolved)	mg/L	0.15	0.76	0.71
Cadmium (dissolved)	mg/L	<0.0001	< 0.001	< 0.001
Chromium (dissolved)	mg/L	0.008	< 0.001	0.007
Cobalt (dissolved)	mg/L	<0.001	< 0.001	< 0.001
Copper (dissolved)	mg/L	<0.001	0.0045	0.003
Iron (dissolved)	mg/L	<0.05	< 0.1	0.06
Manganese (dissolved)	mg/L	0.008	< 0.001	0.007
Molybdenum (dissolved)	mg/L	0.003		0.005
Selenium (dissolved)	mg/L	<0.01	0.005	0.004
Zinc (dissolved)	mg/L	<0.005	0.0115	0.009
Sulphate (dissolved)	mg/L	<1	3.46	3.71
Calcium (dissolved)	mg/L	2	0.16	3.34
Magnesium (dissolved)	mg/L	<1	0.4	1.22
Potassium (dissolved)	mg/L	2	< 0.5	5.27
Sodium (dissolved)	mg/L	359	55.78	1486
TDS	mg/L	845	76	2590

Further geochemical modelling was conducted using the reactive transport module (X1t) in the Geochemists Workbench suite (Bethke, 2009). The simulations involve the injection fluid (80:20 blend, RO permeate to raw CSG water), the aquifer fluid (Gubberamunda Sandstone aquifer water at development site X) and the aquifer medium (i.e. mineralogical composition). The composition of the aquifer medium is defined by the mineralogical analysis, while the injection and aquifer solutions are defined from the hydrochemical analysis. The Geochemists Workbench model results for the injection of the 80:20 blend (RO permeate: raw CSG water) at different dissolved oxygen (DO) concentrations (DO

= 10ppb and 200ppb) produced very similar outcomes with respect to metal concentrations, pH and EC (Figure 1 and Figure 2).

Table 3. *PHREEQC model simulation results for the injection of the various blends into the Gubberamunda Sandstone aquifer at development site X.*

Parameter	**Injection of Blend into Gubbermunda Sandstone (Gubb.)**			
Mix ratio	**50:50 ([A]: Gubb.)**	**50:50 ([B]: Gubb.)**	**50:50 ([C]: Gubb.)**	**50:50 ([D]: Gubb.)**
pH	9.04	8.96	9.1	8.82
pe	-5.93	-5.9	-5.82	-5.77
Alkalinity (mg/ L)	1029	775	1282	643
EC (uS/ cm)	2317	1748	2874	1400
Al (mg/ L)	0.037	0.031	0.043	0.022
B (mg/ L)	0.304	0.253	0.355	0.228
Ba (mg/ L)	0.178	0.118	0.237	0.088
Br (mg/ L)	11.45	15.75	7.14	17.9
Ca (mg/ L)	0.55	0.66	0.49	0.96
Cl (mg/ L)	184	130	238	103
Cu (mg/ L)	0.001	0.0007	0.0013	0.001
F (mg/ L)	1.06	0.64	1.49	0.425
Fe (mg/ L)	0.0207	0.022	0.02	0.024
K (mg/ L)	0.0015	0.002	0.001	0.002
Li (mg/ L)	0.0006	0.0009	0.0004	0.001
Mg (mg/ L)	0.56	0.44	0.68	0.389
Mn (mg/ L)	0.0041	0.0035	0.0047	0.003
Na (mg/ L)	562	418	707	346
P (mg/ L)	0.035	0.021	0.049	0.014
SO4 (mg/ L)	0.924	0.463	1.55	0.24
Sr (mg/ L)	0.241	0.149	0.334	0.103
Zn (mg/ L)	0.0035	0.0031	0.0039	0.003
SAR*	123	93	150	75

There are small change in metal concentration with distance away from the injection point, mainly reflecting the initial concentration of the injection fluid and the initial Gubberamunda aquifer metal constituents (e.g. Figure 3). Precipitation of metal constituents and dissolution of aquifer minerals generally reflect the small variations in aquifer conditions (namely pH), which consequently effects the aquifer metal concentrations. The modelled metal concentrations meet all Australian drinking water guidelines (NHMRC, 2011) and the ANZECC Guidelines (ANZECC, 2000).

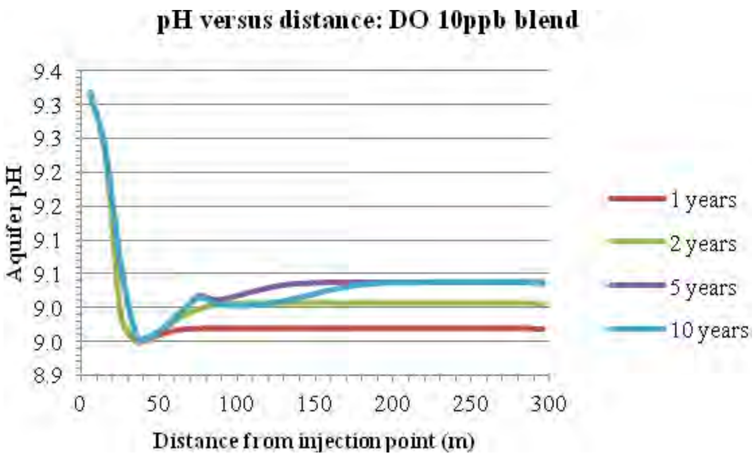

Figure 1. *GWB model simulations for the injection of soultion [D] (80:20 blend of RO permeate and raw CSG water to match the target aguifer TDS which is 845 mg/L) into the Gubbermunda Sandstone aquifer at development site X; pH versus distance at DO = 10ppb.*

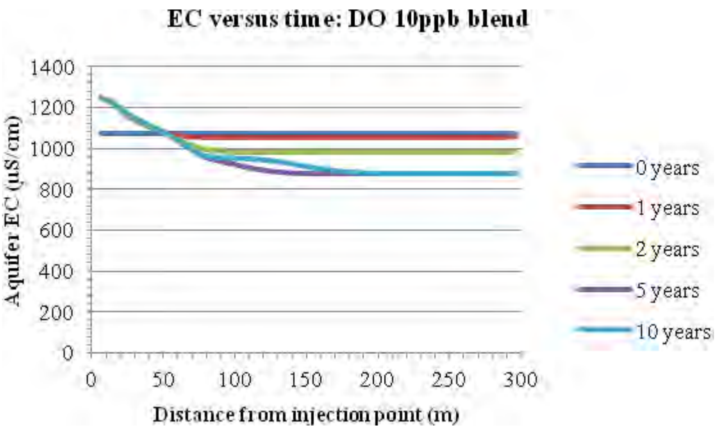

Figure 2. *GWB model simulations for the injection of soultion [D] (80:20 blend of RO permeate and raw CSG water to match the target aguifer TDS which is 845 mg/L) into the Gubbermunda Sandstone aquifer at development site X; EC versus distance at DO = 10ppb.*

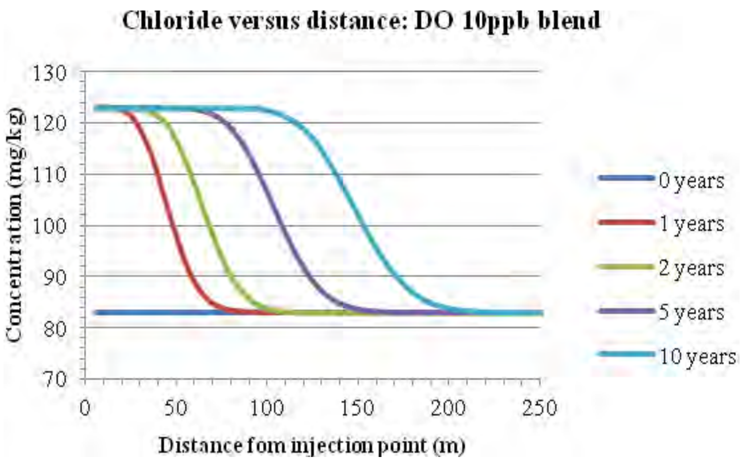

Figure 3. *GWB model simulations for the injection of soultion [D] (80:20 blend of RO permeate and raw CSG water to match the target aguifer TDS which is 845 mg/L) into the Gubbermunda Sandstone aquifer at development site X; Chloride concentration versus distance at DO = 10ppb.*

Conclusions

Based on available information, the proposed injectate is of equivalent or better quality than the receiving Gubbermunda Sandstone aquifer groundwater quality (at development site X). A maximum of approximately 20% raw CSG water can be blended with RO permeate to give an EC equal to or better than the receiving aquifer. Modelling the injections with two different DO concentrations of the injectate indicated that there was little influence of DO concentration (within the range 10ppb to 200ppb) on aquifer chemical parameters. Operation of the injection treatment system within the modelled EC and DO limits suggests that the scheme should meet the basic requirements of success outlined in the National Water Quality Management Strategy's 2009 Managed Aquifer Recharge guidelines (NWQMS, 2009).

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