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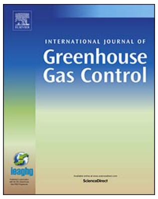

Review

Management and dewatering of brines extracted from geologic carbon storage sites

Jason T. Arena[a], Jinesh C. Jain[a,b], Christina L. Lopano[a], J. Alexandra Hakala[a], Timothy V. Bartholomew[a,c], Meagan S. Mauter[c,d], Nicholas S. Siefert[a,*]

[a] National Energy Technology Laboratory U.S. DOE, Pittsburgh, PA, United States
[b] AECOM Corporation, Pittsburgh, PA, United States
[c] Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA, United States
[d] Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, United States

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ABSTRACT

Subsurface pressure management is a significant challenge in geologic CO_2 storage. Elevated pressure generated from the injection of supercritical CO_2 can be managed by the withdrawal of brine from saline formations before or during CO_2 injection; however, management of the extracted brines is non-trivial because they may have high concentrations of dissolved solids and other contaminants. Dewatering a brine can reduce the volume needing disposal; in addition, water separated from the brine can be a source of usable low salinity water. This review will summarize the composition of brines extracted from select domestic geologic CO_2 storage sites, will calculate the minimum of work of dewatering, and will provide a critical review of developed and developing desalination/dewatering technologies that could be applied to brines extracted from saline formations before or during geologic CO_2 storage operations. Herein are also highlighted, when appropriate, the similarities and the differences between dewatering brines produced from oil/gas operations and brines extracted from geologic CO_2 storage. Since a source of steam or natural gas is likely unavailable/unsuitable for dewatering brines extracted during CO_2 storage, the ideal treatment processes should have a high electrical efficiency and, if possible, should be able to take advantage of the inherent elevated temperature of these brines.

1. Introduction

To continue making use of abundant fossil fuels while simultaneously preventing increased greenhouse gas emissions, there will need to be widespread adoption of CO_2 capture, which is the separation and compression of CO_2 from anthropogenic sources. Following the CO_2 capture step is the geologic CO_2 storage (GCS) step, which is the disposition of CO_2 into those selected subsurface storage formations that present no risk of significant release over geologic time scales (Holloway, 2005; IPCC, 2005; Pires et al., 2011; Varre et al., 2015). The formations available for GCS include: offshore/onshore saline formations, depleted oil and gas wells, and unmineable coal seams (Bachu et al., 2007; Gibson-Poole et al., 2006; IPCC, 2005). Of these, saline formations represent the overwhelming majority of GCS storage capacity with optimistic estimates of CO_2 storage in saline formations suggesting a total CO_2 storage capacity equivalent to at least several decades at current global CO_2 emission rates (Damen et al., 2006; Gale, 2004; Goodman et al., 2011; Potdar and Vishal, 2016). Saline formations are subsurface formations whose available porosity is saturated by saline brine. The ideal saline formation for GCS would be at a depth greater than 800 m such that CO_2 injected within would be in a supercritical state, would be highly permeable so as to minimize the number of injection wells needed, and would be capped by a low permeability seal such as clay or shale (Bachu, 2000; Birkholzer et al., 2009; Holloway, 1997, 2005; IPCC, 2005; Rochelle et al., 1999).

1.1. Brine extraction for GCS risk management

Quantifying the risks associated with CO_2 injection into underground geologic formations has been an active focus area for studies on GCS (Buscheck et al., 2016; Damen et al., 2006; Li and Liu, 2016; Michael et al., 2009; Pawar et al., 2013). In addition to studying the geochemical interactions between aqueous CO_2 moieties and supercritical CO_2 with the formation's structure and mineralogy, a growing area of research in this field is the management of brine displacement and subsequent subsurface pressure build-up within both the storage

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[*] Corresponding author.
E-mail address: nicholas.siefert@netl.doe.gov (N.S. Siefert).

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Nomenclature

Acronyms, abbreviations, and symbols

ED	Electrodialysis
GCS	Geologic carbon dioxide storage
FO	Forward osmosis
MED	Multi-effect distillation
MED-MVC	Multi-effect distillation with mechanical vapor compression
MD	Membrane distillation
MF	Microfiltration
MSF	Multi-stage flash distillation
MVC	Mechanical vapor compression
NF	Nanofiltration
RO	Reverse osmosis
TDS	Total dissolved solids, g/L
TVC	Thermal vapor compression
UF	Ultrafiltration
a_w	Activity of water
m_i	Molal concentration of component i, mol/kg
v_w	Molar volume of water, 0.01797 L/mol @ 25 °C
M_w	Molecular weight of water, 18.02 g/mol
T	Absolute temperature, K
$\dot{w}_{min}/\dot{v}_p$	Minimum work of separation per volume of produced water, kWh/m^3
$\dot{w}_{min}/\dot{v}_b$	Minimum work of dewatering per volume of original brine, kWh/m^3
φ	Osmotic coefficient
π	Osmotic pressure, bar
ρ	Density of water, $0.9970\frac{kg}{L}$ @ 25 °C

formation and any overlying formations (Birkholzer and Zhou, 2009; Buscheck et al., 2016, 2011; Cihan et al., 2015; Gaus, 2010; IPCC, 2005). Excess formation pressure can cause seismic events and/or drive CO_2 leakage through pre-existing wells in the formation or through natural faults with the potential to hydraulically fracture the formation seals (Lee et al., 2016; Varre et al., 2015). Accumulation of subsurface pressure might require lower rates of CO_2 injection and possibly reduce a formation's CO_2 capacity. One mitigation strategy is to extract brine from a saline formation before and/or during CO_2 injection, reducing reservoir pressure and allowing for higher rates of CO_2 injection and greater storage capcity (Buscheck et al., 2016, 2011; Cihan et al., 2015; IEAGHG, 2012). The optimal extraction ratio, which is the volume of brine extracted for pressure management normalized by the volume of CO_2 injected, is largely formation dependent. Open and highly porous formations will permit a lower extraction ratio than formations that are closed, have low porosity, or are close to active faults. Because these formations present a greater risk to overpressure, they require a higher extraction ratio (Bourcier et al., 2011; IEAGHG, 2012; IPCC, 2005). In the case of a deep sandstone formation near active faults with a CO_2 injection rate of 5 Mt/yr, the volume of extracted brine was estimated to be 38–67% of the volume of injected supercritical CO_2. This value was developed from an optimization of extraction well placement and extraction ratio to prevent the escape of CO_2 through the extraction wells and maintain formation pressure below 1 MPa (Cihan et al., 2015).

While brine extraction can be used to manage a formation's pressure, a required next step is the disposition of the produced brine. Typically, these brines are sufficiently saline such that they cannot be used for domestic, industrial or agricultural purposes (Bourcier et al., 2011; Veil et al., 2011). In the disposition of these brines, isolation from formations used for industrial, agricultural, and drinking water are paramount; therefore, disposal into surface waters is not a viable option (Birkholzer and Zhou, 2009; Lemieux, 2011). One possible solution is to dewater these brines, such that the brine, now having a reduced volume and higher concentration of dissolved solutes, can be reinjected with a net reduction in subsurface volume. The product water should be of sufficient quality that it could be used for industrial or agricultural purposes or discharged into surface waters (Aines et al., 2011; Bourcier

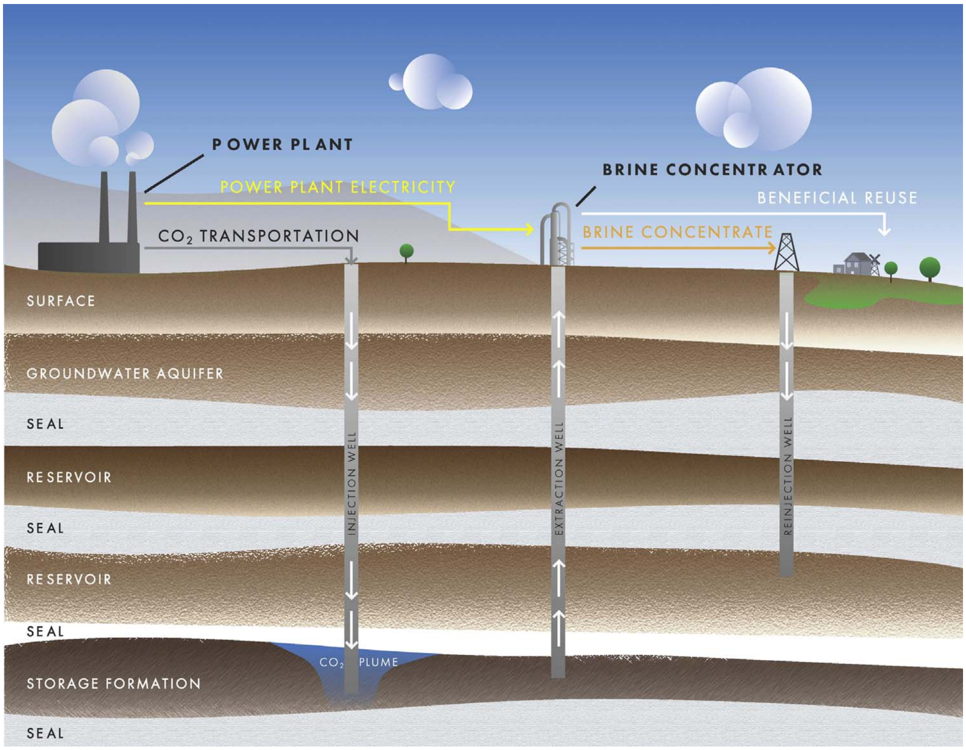

Fig. 1. Schematic illustrating GCS operations. Image courtesy of Jacob Howell. Note: Geology not to scale.