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A review on CO_2 leakage detection in shallow subsurface using geophysical surveys

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ABSTRACT

Carbon capture and storage via the injection of carbon dioxide (CO_2) into deep saline aquifers, also known as geological storage of CO_2, has been used to mitigate greenhouse gas emissions. However, geologically sequestered CO_2 can seep out through leaky wells and faults, thereby contaminating groundwater and reaching the atmosphere. Several facilities for controlled injection of CO_2 into the shallow subsurface have been constructed to enhance understanding of the impacts of CO_2 on the physical properties of the subsurface and to improve the early detection of CO_2 leakage, before it reaches the atmosphere. Among various monitoring methods, geophysical methods have been employed widely to detect CO_2 plume migration at shallow depths before CO_2 enters the atmosphere. In this study, geophysical monitoring during CO_2 injection at eight field sites and in five laboratory experiments was reviewed and analyzed. The analysis encompassed not only changes in subsurface geophysical properties, such as bulk electrical resistivity, complex resistivity, induced-polarization parameters, and electrical permittivity related to the presence of CO_2, but also the effects of geological conditions on changes in these geophysical properties. Case studies of geophysical monitoring for natural CO_2 leakage from gas vents are also discussed to provide real examples of CO_2 degassing and leakage into the atmosphere. Geophysical surveys are sufficiently effective and sensitive for the monitoring of changes in geophysical properties due to the presence of CO_2 leaked from sequestration reservoirs, and will be much more effective after the identification of high-risk regions for CO_2 leakage from the Earth's surface.

1. Introduction

Among greenhouse gases, carbon dioxide (CO_2) is the most critical driver of global climate change. The greatest portion of CO_2 emissions arises from the combustion of fossil fuels for electricity generation, heat production, and industrial needs (US EPA, 2017). Carbon capture and storage (CCS), in which CO_2 is captured from industrial and energy-related sources for storage (IPCC, 2005), can effectively reduce the amount of CO_2 in the atmosphere (IEA, 2011). Among several storage methods, geological sequestration enables storage of the greatest amount of CO_2.

CO_2 has been sequestered in geological trap structures at depths ranging from 600 m to 2 km at several test-bed sites: Sleipner site, Norway (Alnes et al., 2011; Arts et al., 2008; Chadwick et al., 2014; Park et al., 2013, 2017; 2011), Ketzin, Germany (Bergmann et al., 2016; Kiessling et al., 2010), and FutureGen site, USA (Strickland et al., 2014). CO_2 can also be stored in hydrocarbon reservoirs during CO_2-based enhanced oil and gas recovery, as performed in Cranfield, USA (Carrigan et al., 2009; Carrigan et al., 2013; Dodds et al., 2013) and Jilin, China (Ren et al., 2016).

However, such geologically sequestered CO_2 might leak through unexpected faults or abandoned wells into overlying permeable formations. As CO_2 released into the atmosphere can pose a threat not only to nature, but also to human life, the monitoring of CO_2 leakage at geological sequestration sites is critically important. Although CO_2 leakage from sequestration trap structures can occur, the migration of leaked CO_2 to the shallow subsurface in the absence of nearby boreholes or faults takes a long time, especially in areas far from injection points to which the gas has migrated (IPCC et al., 2005; Barrio et al., 2013; Lee et al., 2016). Thus, geophysical and geochemical methods have been used to deliberately inject CO_2 into the shallow subsurface in monitoring studies, to enable the analysis of leakage over shorter time scales and to investigate early leak detection (Lee et al., 2016).

To elucidate the impacts of CO_2 on the subsurface and the migration of the CO_2 plume, geochemical and geophysical methods may be employed. Geochemical monitoring involves the analysis of water

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