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Field measurement of residual carbon dioxide saturation using reactive ester tracers

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ABSTRACT

As part of the CO2CRC Otway Residual Saturation and Dissolution Test, a series of field tests were conducted at their project site in Victoria, Australia, with the primary goal of developing and assessing methods for quantifying residual CO_2 saturation in a saline aquifer. This paper reports the outcome of one of these tests, a single-well "push–pull" tracer test that uses novel reactive esters (i.e., propylene glycol diacetate, triacetin and tripropionin). For this tracer test, the ester is injected (pushed) into the reservoir where residual saturation has been established using CO_2, and maintained by pushing with CO_2 saturated water (to prevent changes in saturation due to CO_2 dissolution). The ester is partially hydrolysed by the formation water to yield multiple compounds (i.e., the corresponding alcohol and acid generated from the ester). During water production (pull) from the same well, these compounds will partition differentially between the residual supercritical carbon dioxide phase and water phase, leading to chromatographic separation. By modelling the concentration profiles of these tracers in production water samples and using the experimentally determined partition coefficients, we generate two consistent residual saturation estimates using two separate modelling techniques, one a simple finite difference simulation of the tracer velocity field and the other a standard multiphase simulation code.

1. Introduction

The widely acknowledged trapping mechanisms for CO_2 storage in saline aquifers or depleted hydrocarbon fields (i.e., structural/stratigraphic, mineral, solution and residual) contribute, to varying degrees, to the overall storage capacity. Furthermore, their quantitative contribution varies over time (see Fig. 1). As the amount of residual trapping is such a quantitatively significant contributor to long-term storage, being able to measure the amount of residual saturation to estimate likely storage capacity of a site is critical. Previous investigations have reported that immediately after injection, residual CO_2 trapping is estimated to contribute between 20 and 40% of the overall CO_2 trapping capacity in a formation (Flett et al., 2007; Ide et al., 2007; Bennion and Bachu, 2008; Suekane et al., 2008). Thus a more accurate determination of residual CO_2 saturation capacity will allow storage mechanism models to be further constrained and estimates of overall storage capacity to be improved. One option to measure residual saturation is with a pulsed neutron tool (more commonly known as either a reservoir saturation tool or RST and is often used to determine water saturation). This technique was used at the Frio Brine Pilot Experiment in the Texas Gulf Coast to determine the dynamics of CO_2 saturation during injection and post-injection periods (Sakurai et al., 2006; Muller et al., 2007). At the Nagaoka test site in Japan, time-lapse RST has also been used to monitor the approach to residual CO_2 saturation during the post-injection imbibition phase (Xue et al., 2006; Mito and Xue, 2011). However, the RST method is only sensitive to the near well bore environment (i.e., neutron penetration is limited to approximately 0.25 m) and may not be truly indicative of the reservoir formation. This tool was also used at three discrete points during the CO2CRC Otway Residual Saturation and Dissolution Test (Paterson et al., 2013). A variety of other tools and methods were also tested at Otway that had different radii of examination providing information on the heterogeneity of the formation tested and allowing comparisons to be drawn. This series of tests included a reactive ester tracer test to determine its efficacy as a method for measuring residual saturation in storage intervals and is the subject of this paper.

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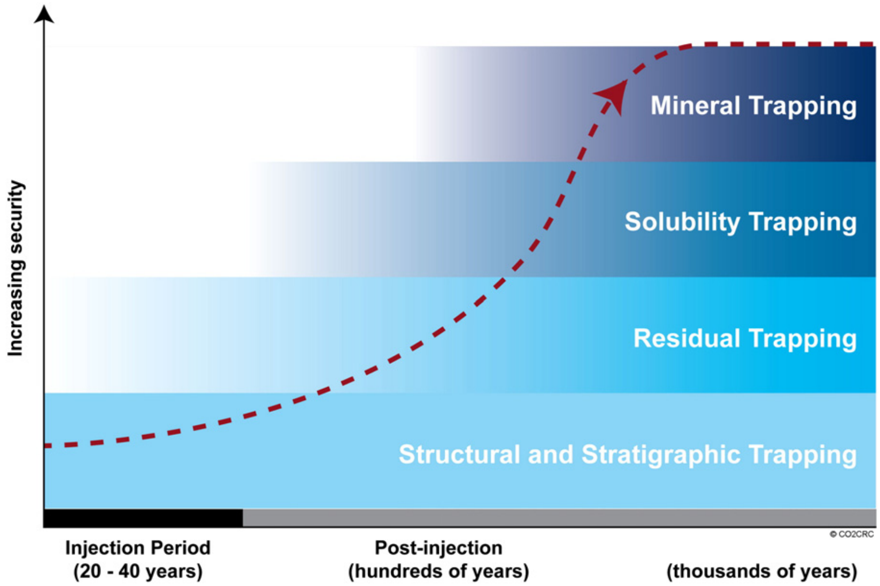

Fig. 1. Schematic diagram showing evolution of the four key trapping mechanism contributions over time to the storage capacity of a containment site showing that residual trapping is a key mechanism.

1.1. The CO2CRC Otway Residual Saturation and Dissolution Test

In mid-2011, the CO2CRC Otway Residual Saturation and Dissolution Test evaluated a series of field-based methods. While field trials are more complex and expensive, the progression from lab scale core flooding tests and/or modelling techniques to field tests moves towards reducing uncertainties related to the level up-scaling required for commercial scale activities. A suite of complementary tests developed to determine the residual CO_2 saturation of a formation was proposed and the viability of each of these techniques was evaluated using computational simulations (Zhang et al., 2011). Many of these tests were subsequently conducted after the CRC-2 well was drilled in Jan/Feb 2010 in the Cretaceous age Paaratte Formation. The field tests included both physical and chemical measurements following detailed characterisation of the perforated formation interval prior to testing. The following tests (Paterson et al., 2013) were conducted after establishing residual CO_2 saturation (by injecting pure CO_2 followed by CO_2 saturated water) as part of the Otway Residual Gas Saturation Test (see Fig. 2):

1. Pressure response measurements using four gauges set within the perforated interval to measure bulk permeability and flow behaviour for water and CO_2 injection and recover and residual saturation of CO_2. This method has a wide area of interrogation in the range of metres.
2. Pulsed neutron logging (reservoir saturation tool [RST]) repeat tests were conducted over a 255 m interval including the perforated inter-

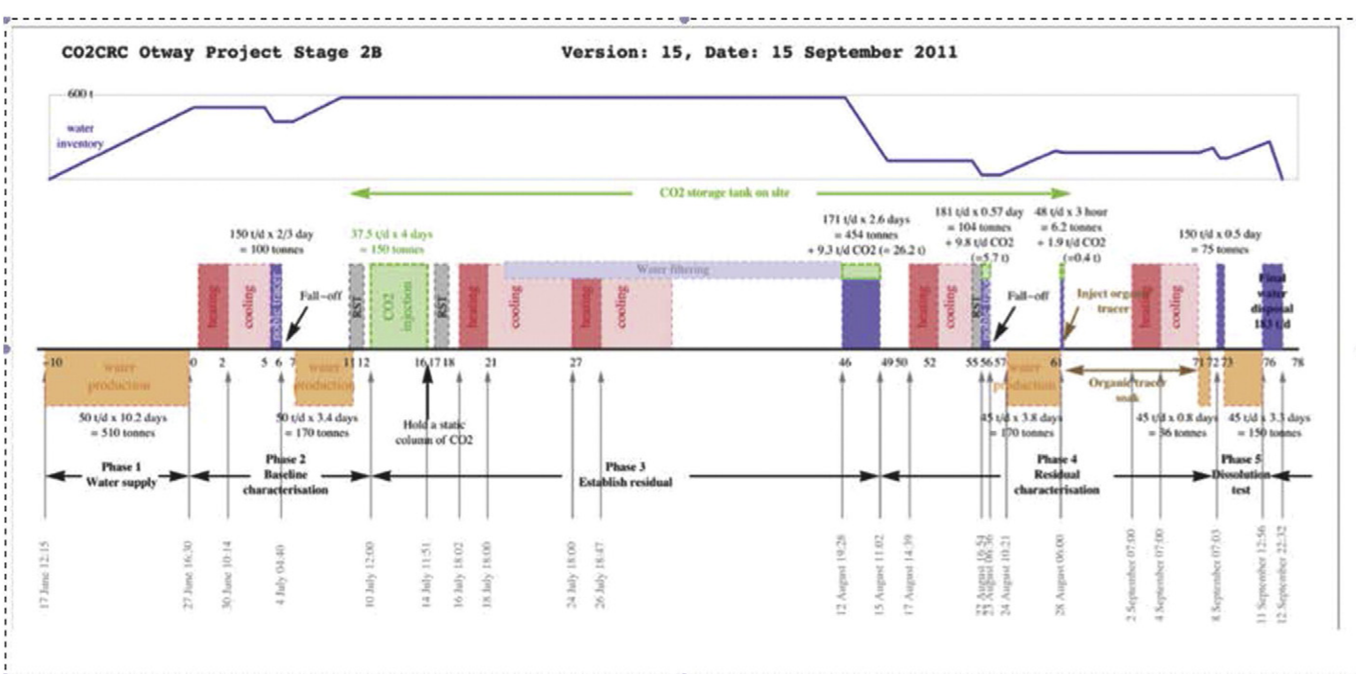

Fig. 2. Full Otway test sequence, after Paterson et al. (2013).