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Wellbore integrity and corrosion of carbon steel in CO_2 geologic storage environments: A literature review

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ABSTRACT

Depleted oil and gas fields are attractive candidates for carbon capture and storage (CCS). As it contemplates the transition from CO_2 enhanced oil recovery (EOR) to CCS, the Weyburn–Midale CO_2 project is one such site. In the long-term risk assessment for Weyburn–Midale, wellbore integrity was identified as being a significant risk factor with respect to the permanence of CO_2 sequestration. In an optimal situation, cementing will be good for both completion and abandonment; contact of CO_2 with casing will be governed by cement permeability and interface effects. However, in the event of there being a poorly cemented casing-hole annular space, a more direct contact between the now “wet” injected CO_2 and the casing steel will be possible. Consequently, this will lead to corrosion of the steel and the potential for CO_2 leakage. The corrosion rate of carbon steel under high CO_2 pressure without protective $FeCO_3$ is very high (~20 mm/year). At certain conditions, the corrosion rate can decrease to low values (~0.2 mm/year) in long-term exposure due to the formation of a protective layer of $FeCO_3$.

1. Introduction

Mature oil and gas fields represent attractive candidates for the geologic storage of CO_2. Such sites are well characterized, host formations are overlain by impermeable caprock that permitted hydrocarbon accumulation and operators have experience with the chemistries encountered in wellbore environments (sour character, brine, *etc.*).

Weyburn and Midale, depleted oil and gas fields located in southeast Saskatchewan, Canada and operated by Cenovus and Apache, respectively, are examples of such sites. Over the last decade the operators have used CO_2, from Dakota Gasification's Great Plains Synfuels Plant in their enhanced oil recovery (EOR) operations to facilitate and extend production from these fields. Over 4500 wells exist at Weyburn–Midale in the area where CO_2 injection is occurring (Wilson and Monea, 2004). As the fields reach the end of their production lives, they may be utilized for deep geologic storage of CO_2. The reservoir comprises limestone (primarily calcite ($CaCO_3$)) and dolostone (primarily dolomite ($CaMg[CO_3]_2$)). Variable secondary amounts of quartz and metal (alumino) silicates are also present. The contained brine consists primarily of Na^+, Cl^-, Ca^{2+} and $SO_4{}^{2-}$. The caprock (or “primary seal”) is the Midale Evaporite unit, which is comprised primarily of anhydrite, and the ultimate seal is the Watrous Formation, a regionally extensive aquitard comprising siliciclastics (notably, tight siltstones) with anhydritic and dolomitic cements. In spite of favorable geology, in the long-term risk assessment for the storage site, wellbore integrity was identified as being a significant risk factor with respect to the permanence of CO_2 sequestration.

Particular “Features, Events and Processes”, or “FEPs”, listed as being relevant to the Weyburn system that were specific to abandoned wells included the quality/integrity of annular space, unsealed boreholes, corrosion of casing, corrosion products, seal degradation and incomplete records of abandonment/sealing (Chalaturnyk et al., 2004). Therefore, prior to discussion of corrosion, consideration is given to cementing as this plays a key role in determining how dissolved CO_2 may contact the casing. In addition to zonal isolation, cement helps confer protection to casing against corrosive fluids.

2. Cementing and corrosion

In principle, casings are cemented upon completion and plugged upon abandonment to ensure isolation of the zone containing the sequestered CO_2. An ideal, simplified abandoned well is depicted in Fig. 1. Note that the annular space between the casing and the rock is completely filled with cement, and the plug top is located within the caprock, thus ensuring isolation of the production zone. Therefore, if the casing is to come in contact with CO_2 saturated brine within the production zone/formation rock, the cement sheath itself must be infiltrated.

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