geoconvention
Calgary · Canada · May 15-17 2023

Well Integrity Monitoring at CCS Projects: A Case Study

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Summary:

Protracted, periodic gas monitoring informs the protection of surface and groundwater resources and characterizes the containment and conformance of injected CO_2. At the CMC Newell County Facility, a gas-phase CCS program near Brooks, one well produces gas, and three wells have non-serious surface casing vent (SCV) emissions comprised primarily of naturally derived CO_2 and CH_4. Injected CO_2 is not present in any samples. At all sources CO_2 declined during a four-year interval. The injected gas is enriched in inherent chemical tracers that can also show injected CO_2 is absent from samples. The CH_4 component from two SCV's, on the injector and geophysical observation well, remained similar over four years. CH_4 produced at the geochemical observation well and the isotopically different CH_4 emitted from its SCV both declined progressively from 2018 to 2020. In 2020 CH_4 increased at this SCV, but not in the well. By 2022 CH_4 from this SCV was, for the first time, as abundant as in samples from the other two SCVs. Temporal changes in δ^2H_{CH4} ratios also occurred pervasively and synchronously in 2020. These indicate changes in storage complex microbial methanogenesis. While, NCF wells lack constructed integrity, the injected CO_2, is absent from sources studied and the SCVs are inferred isolated from the injected CO_2 plume.

Introduction:

The Carbon Management Canada Inc. Newell County Facility (NCF) is a shallow gas-phase CO_2 pore space storage project in southeastern Alberta, about 26 km SW of Brooks (Lawton et al., 2017). The primary purpose is to test and develop measurement and monitoring technologies and techniques. In general, CO_2 injection, at low rates and volumes, is used to test the detection threshold and performance of monitoring technologies that could identify a loss of containment, or a departure from conformance above a hypothetical deeper and larger CCS storage complex, protecting groundwater and shallower resources and environments. Upper Cretaceous Belly River Gp. bedrock storage complex, predominantly sandstone, coal and mudstone, outcrops directly below Pleistocene glacial till and sediments ~25 m thick. The site has three Alberta Energy Regulator wells, each equipped with a SCV (Wigston et al., 2020). These include an injector (100-10-22-17-16W4), a geochemically-oriented observation well (well #2, 200-10-22-17-16W4), and a geophysically-oriented observation well (well #3, 300-10-22-17-16W4). The three wells align along the dip azimuth with the injector located 20 m up dip of well #3 and well #2 located 30 m up dip of the injector. The base of groundwater protection is ~220 m deep. Local groundwater resources are non-potable. Gaseous CO_2 injection occurs into Belly River Group basal shoreface sandstones (291-298 m depth). CO_2 injeciton commenced in August 2017. All three SCV's emit sweet CH_4-rich natural gas at low rates. The highest and most consistent emission rate is from the SCV on well #3, which has emitted at ~0.87 m^3/day since the well was constructed in February 2016. Subsequently both other wells developed non-serious SCV flows. The SCV flow at well #2 was first observed April 5th, 2016. This well communicates with injection zone strata through a sand-packed and screened casing completion. A U-tube sampler (Freifeld et al., 2005) in that well lands in the sand pack on the exterior of the screened casing interval. A flow of natural gas into well #2 followed the removal of the water column to facilitate a cross-hole geophysical survey in mid-October 2017. The gas flow was then suppressed by the introduction of a KCl weighted water. Injector SCV flow was first measured October 4th, 2018. Unpublished observations indicate no impact of the CO_2 injection program on the SCV rates or the pressure and water level in well #2. This suggests all three wells were, as of January 2022, isolated from the direct migration of injected CO_2 into any of the cemented or sand packed well annuli. At the NCF there are six water wells, none much more than ~100 m deep. Other facilities, additional site details and programs are discussed elsewhere (Macquet et al., 2019; Goodarzi et al., 2019; Yu et al., 2020; Macquet et al., 2022).

Previous work:

Mayer et al. (2015) produced cuttings and mud gas logs during the construction of the injector and well #2. Vinson et al. (2017) reassessed microbial CH_4-rich natural gas and suggested revision of widely accepted isotopically-based interpretational frameworks. A baseline NCF geochemical survey, including noble gases, used samples collected between March 2017 and May 2018 that included commercial CO_2 from the supplier of NCF injected gas (Utley et al., 2023). Utting et al. (2022) evaluated analytical approaches to environmental monitoring with natural gas samples from the NCF. They used a field portable quadrupole mass spectrometer as compared to laboratory-based magnetic sector mass spectrometry, gas chromatography and stable isotope ratio determinations.

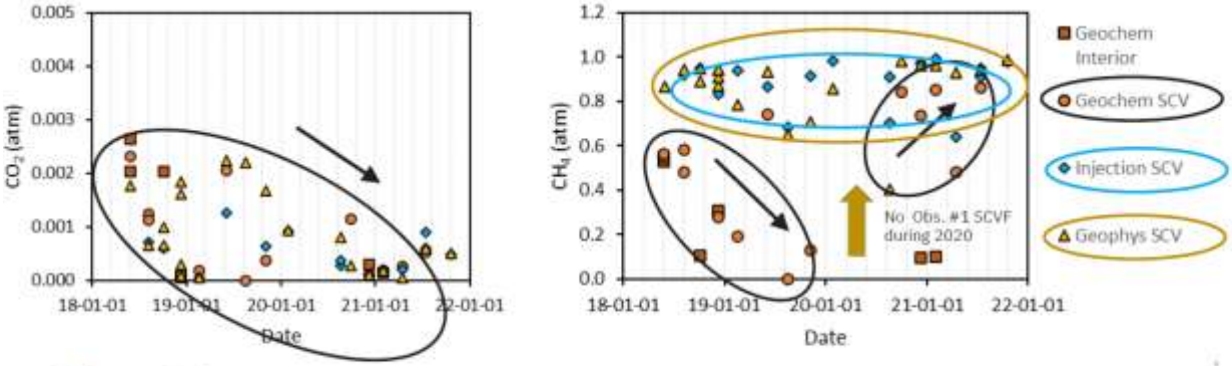


Figure 1: CO_2 and CH_4 gases emitted from three surface casing vents and the interior of well #2 over a four-year interval, January 2018 to January 2022. Initial data set collected May 2018 appears in Utley et al. (2023, Table 1). Data collected after May 2018 until January 2020 appears in Utting et al. (2022, Table 1). Data collected after January 2020 is unpublished.

Observed CH_4 and CO_2 Compositional and Isotopic Ratio Variations:

Quarterly fluid sampling May 2018 to January 2022 (Figures 1 and 2), provided gas samples discussed herein. In general, CO_2 became less abundant in samples from all four sources with time (Figure 1). This was initially mimicked by a decline in CH_4 from the interior of well #2 and its SCV. In contrast, the abundance of CH_4 emitted from the SCV's at both the injector and well #3 remained generally constant throughout the four-year period. Except for the interior of well #2, we observed a synchronous change in both the abundance of CH_4 emitted from the SCV on well #2 and the stable isotopic ratios of all methane sources during late Summer 2020. By the beginning of 2022 the CH_4 from all three SCV's and their associated δ^2H_{CH4} ratios achieved a similarity not seen previously, that also distinguished them all from the gas produced from well #2.

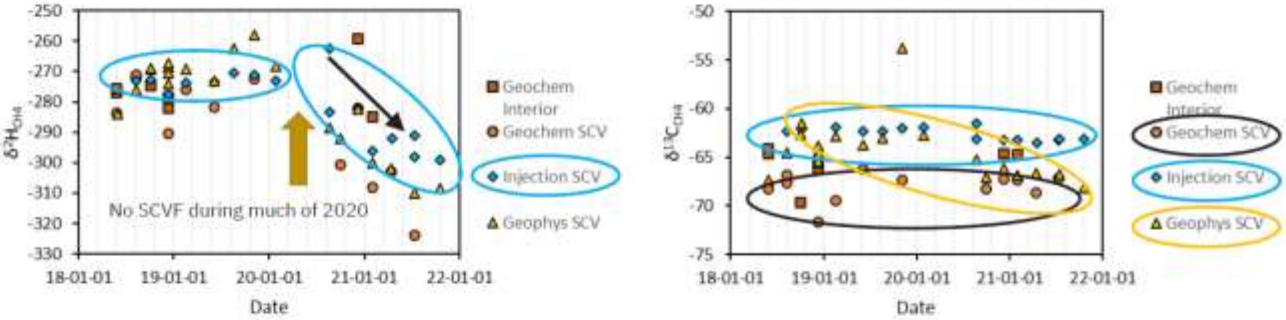
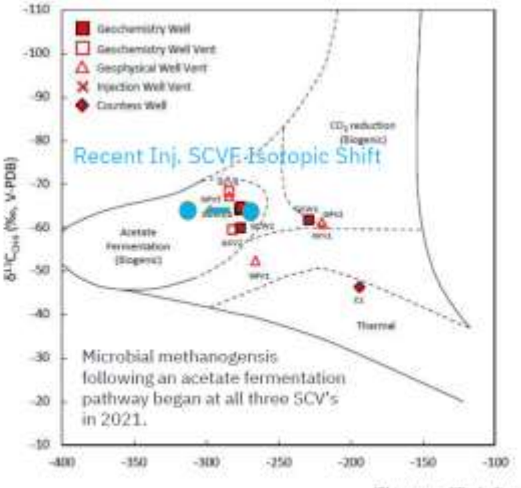


Figure 2: Deuterium and Carbon isotopes of CH_4 emitted from three surface casing vents and the interior of well #2 over a four-year interval, January 2018- January 2022. Initial data set collected May 2018 appears in Utley et al. (2023, Table 1). Data collected after May 2018 until January 2020 appears in Utting et al. (2022, Table 1). Data collected after January 2020 is unpublished.

There were no samplable flows from several features early in 2020, due to gas flow TSTM. At the end of 2020 samples were again obtained from all features. At the SCV on well #2 the CH_4 component was as high or higher than that observed prior to the start of 2020. In contrast, samples produced from well #2 remained as low or lower than that observed prior to 2020 (Figure 1).



(Figure modified after Utley et al., in review)

Figure 3: Whiticar (1999) diagram modified from Utley et al. (2023, their Figure 4) of $\delta^{13}C_{CH4}$ and δ^2H_{CH4} of SCV CH_4 indicating the change in emitted CH_4 isotopic composition since 2021.

Sample $\delta^{13}C_{CH4}$ is distinguishable at each of the four features (Figure 2). The carbon isotopic ratios remain constant over time at the Injector SCV, the interior of well #1 and its SCV. Yet each feature is distinguished from the other by its relative isotopic depletion. At the SCV on well #3 we observed a temporal trend of progressive carbon isotopic depletion. That depletion trend spans the range of relative $\delta^{13}C_{CH4}$ difference observed among samples from the other three features. In contrast, all of the sources exhibited relatively constant δ^2H_{CH4} ratios until the start of 2020, after which all sources exhibited a significant and progressively increasing δ^2H_{CH4} depletion beginning in the second half of 2020 that continued into 2022. In general, gas from the SCV on well #2 was the most depleted. There was, relatively, less δ^2H_{CH4} depletion in samples from the SCV's of well #3 and the injector. Using the changes in gas stable isotopic ratios from the SCV on the injector (Figure 3), the changes in isotopic ratios suggest that the more recently collected samples plot deeper in the standard field of microbial acetate fermentation, or demethylation. This suggests that CH_4 is being actively generated from coals and coaly material in the storage complex. Vinson et al. (2017) would likely ascribe this CH_4 to microbial CO_2 reduction rather than microbial acetoclastic processes. Unfortunately, the SCV and wellhead samples are dry gases lacking co-existing water that might clarify the methanogenic pathway. Still, the progressive δ^2H_{CH4} depletion indicates a change in storage complex microbial methanogenesis. Where the earlier general exhaustion of CH_4 and CO_2 at some features suggested that those gases were the product of laborious kinetics, the more recently generated gas with more depleted δ^2H_{CH4} ratios may be produced more rapidly.

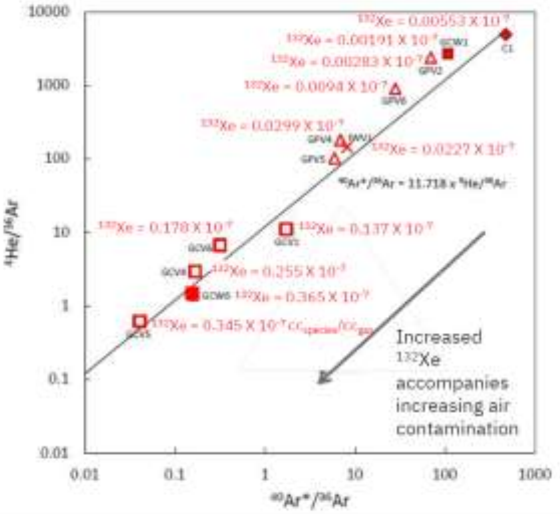


Figure 4: Modified after Utley et al. (2023, their Figure 7, annotated with ^{132}Xe data from their Table 2). The CH_4-rich natural gases from the producing wells have lower 132Xe abundance and that 132Xe concentration (ccSTP/cc) increases as the ratios of select noble gas components (^4He, ^{36}Ar, $^{40}Ar^*$, ^{132}Xe) decreases.

The composition and isotopic ratios of the injected gas differs from samples that are either produced from Viking Fm (C1) and Foremost Fm. (GCW=well #2) at NCF or collected at the three SCV's (Figure 4, Utley et al., 2023). None of the sources have $^{132}Xe/^{36}Ar$ ratios > 0.01 where $^{132}Xe/^{36}Ar > 1.0$ in the sampled CO_2. Air mixing variably affects gas samples. Samples from wells, have the lowest ^{132}Xe relative to ^{36}Ar. Samples from the SCV on well #3, with the highest SCV flow rate have the next lowest abundance of ^{132}Xe relative to ^{36}Ar. The highest $^{132}Xe/^{36}Ar$ appear in samples from the SCV on well #2, that emits at lower rates, sometimes intermittently.

Discussion:

The CH_4 and CO_2 compositions and stable isotopic ratio characteristics indicate no presence of the injected CO_2 in any samples from any of the well features, as of January 2022. During this study the CO_2 component of natural gases appears to have declined significantly. Henc the injected CO_2 plume has not arrived, or arrived unaltered. CH_4 generation in the storage complex is inferred to be ongoing, as indicated by changes observed in late 2020. Composition of the injected CO_2 is easily distinguished from local natural gases. Utley et al. (2023) observed enrichment of ^{132}Xe relative to ^{36}Ar, in their CO_2 samples and a relative decrease in $^4He/^{36}Ar$ as a function of radiogenic $^{40}Ar^*/^{36}Ar$. This is accompanied by an increase in ^{132}Xe (Figure 4). The mixing of natural gas with air at the wells and SCV's is expected considering that SCV's are commonly, and the well interiors are sometimes, connected to the atmosphere. The future appearance of injected CO_2 at any NCF emission source could be confirmed by a three-component gas composition mixing model (see Utley et al., 2023 their Figures 10 and 11).

Conclusions:

Well integrity contributes to CCS containment monitoring and conformance verification. Non-serious CH_4 emissions from well #2 and all the SCVs are generated by biogenic processes in the storage complex, both previously and currently. The significance of differences in the stable isotopic ratios of natural gases collected at different wells and their SCVs remains to be updated and interpreted fully. The injected CO_2 gas plume has not arrived at the sand packed injection zone at well #2, nor at any SCV samples. Thus, while there is a lack of general well integrity the SCV samples suggest storage complex isolation and integrity at all three wells until the beginning of 2022. Neither has the injected plume arrived at the injection zone sand pack and screened completion at well #2. Trace, especially noble gas, components intrinsic to the injected CO_2 provide potential tracers that can indicated migration pathways and gas mixing. ^{132}Xe is a potentially useful tracer that occurs in both the CO_2 from the supplier of the injected gases and the atmosphere, but which is much less abundant in the indigenous natural gases at the NCF.

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