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Monitoring a 120-kg CO_2 injection in a coal seam with continuous gas and microseismic measurements (European RFCS CARBOLAB research project)

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Abstract

INERIS has monitored a CO_2 injection test performed in a coal seam. Both passive seismic monitoring and gas monitoring have been performed prior, during and after the injection test. Gas migration was not monitored in coal because leakage occurred during the injection. Nevertheless, passive seismic monitoring and continuous gas monitoring proved here to be valuable tools to observe gas migration and the behaviour of the rock during the injection test. They also helped to understand the discrepancies between observations and predictions, which can be useful to draw recommendations for future tests.

Keywords: ECBM ; CO_2 ; injection ; microseismic monitoring ; geochemical monitoring.

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1. Introduction

1.1. The RFCS CARBOLAB research project

The main goal of the RFCS CARBOLAB research project was to fill the gap concerning the lack of data and comprehension of the physicochemical mechanisms that exist between laboratory experiments on gas adsorption properties of coal and full-scale CO_2 injection tests from the surface. This project was funded by European commission through the Research Fund for Coal and Steel from 2009 to 2013.

Gathering Spanish (HUNOSA, AITEMIN), French (BRGM, INERIS) and Polish (GIG) partners, the project contained three main actions: laboratory tests, numerical modeling and in-situ injection at a seam scale. The injection site was within an existing underground infrastructure, a crosscut of a coal mine located in Asturias (North of Spain) and owned by HUNOSA (project coordinator). This article details the geochemical and geophysical monitoring of the injection test. For further details on laboratory tests, see [1].

1.2. Injection test

Injection of CO_2 in coal can enhance methane recovery. This technique known as CO_2-ECBM (Enhanced coal bed methane recovery) can be used in conjunction with carbon capture and storage to mitigate anthropogenic CO_2 emissions. Several CO_2-ECBM pilot tests have been carried out worldwide, but in conditions which are quite different from the European deposits (e.g. highly permeable coal deposits, such as that exploited in the United States). The only tests carried out in Europe so far are those carried out within the RECOPOL project. But this project didn't make it possible to demonstrate the control of the true process of CO_2 sequestration in European coals. The CARBOLAB project intended to advance in this specific target, by performing injection tests from underground, in order to save costs and to improve the experiment control by reducing the size of the test dimension.

The CARBOLAB experiment took place in a mine gallery and consisted of injecting CO_2 into the center of an approximately 4 m thick and vertical coal seam, then monitoring the outcome of the CO_2 “bubble” using monitoring devices previously installed in boreholes surrounding the area of injection. Injection period started on 3 July 2013 and ended on 10 September 2013. HUNOSA and AITEMIN have monitored injection flow and injection pressure at the bottom of the injection borehole. Injected gas was pure CO_2. Unfortunately, injection was not a continuous process as it was disrupted by several events. Main injection period was from 3 July 2013 to 7 August 2013 with a mean injection flow of 108.4 Nl_{CO2}/h (max. reached 500 Nl_{CO2}/h on very short time periods) and a mean bottomhole injection pressure of 20 bar (fig. 1). Taking into account leakage that has been detected (see later in this article), the total injected quantity is about 120 kg of CO_2.

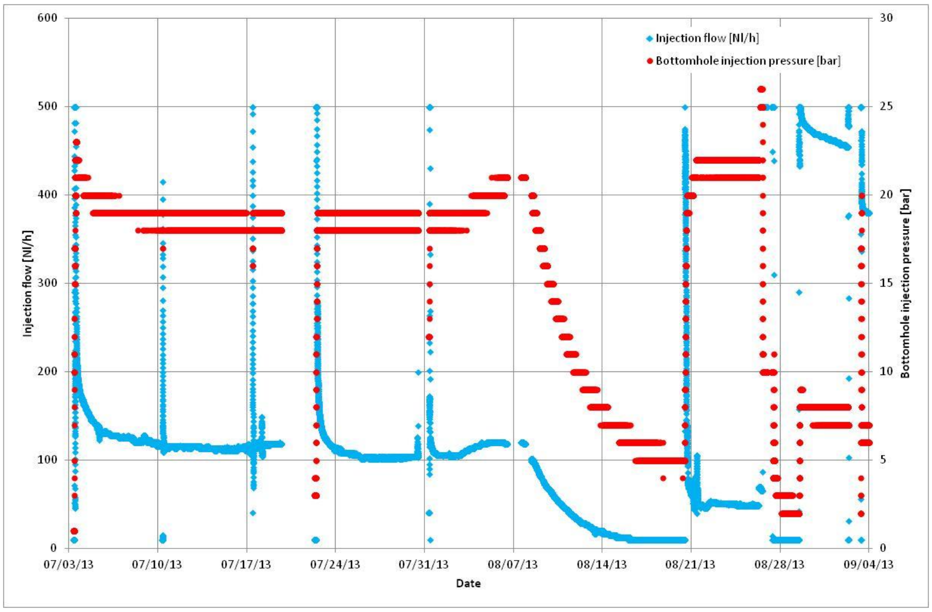

Fig. 1. Injection flow and bottomhole injection pressure during the injection. Data from HUNOSA and AITEMIN.

BRGM and INERIS were both involved in the monitoring of the injection test (see [2] for further details on BRGM contribution). INERIS performed microseismic monitoring (passive seismic monitoring), continuous gas monitoring in boreholes drilled in coal and surrounding rocks, and also gas flux measurements at the floor and on the wall of the crosscut.

2. Experimental site and monitoring equipments

HUNOSA built an experimental site by drilling 21 boreholes (diameters ~96mm and lengths from 30 to 50 meters) from a crosscut that intersects an unexploited 2-m width vertical coal seam. AITEMIN designed the injection panel. Injection point was located directly in the coal seam at about 30 meters from the wall of the crosscut. Geochemical and geophysical monitoring boreholes were drilled in coal close to the injection point and in the surrounding rock strata (shales and sandstones).

In 2012, INERIS installed and tested monitoring equipments as described in [3,4] and on figure 2. These equipments have monitored the coal seam during the baseline study that ended with the start of the injection on the 3d of July 2013. Injection period (from 3 July to 10 September 2013) and post-injection period have also been monitored. Monitoring systems have been shut down about 2 months after the end of the injection.

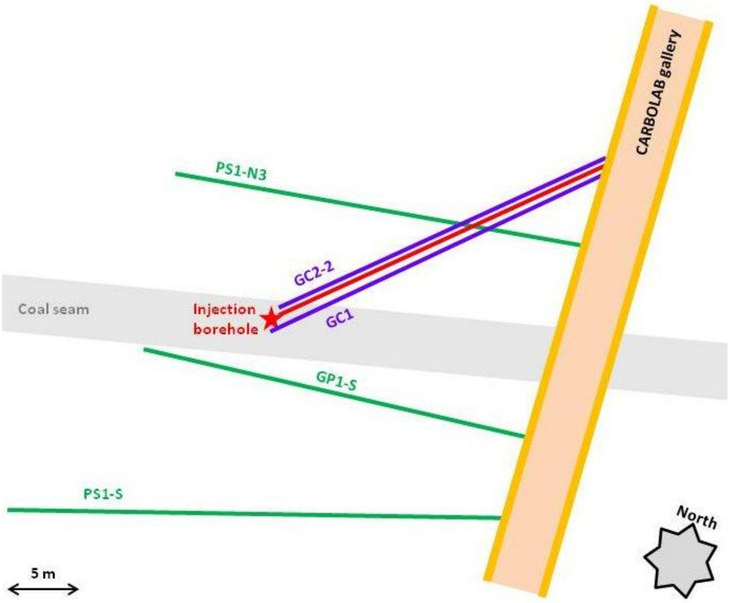

Fig. 2. Top view of the coal seam (grey), the CARBOLAB gallery (orange) and the drilled boreholes (injection borehole in red; boreholes dedicated to geochemical monitoring in purple; boreholes dedicated to geophysical monitoring in green).

3. Microseismic monitoring

The goal of the microseismic monitoring was to collect relevant information on the outcome of the CO_2 bubble within the coal seam as well as on any possible mechanical ruptures in the coal and the surrounding rocks generated by the injection. This goal involved (1) evaluating the technical feasibility of the microseismic monitoring in the context of the site and (2) characterizing the microseismic activity (number of events and their energy) in correlation with the injection parameters and, if possible, locating the rupture sources.

3.1. Microseismic instrumentation

The installed device consists of two 50-m long arrays of 7 and 8 hydrophone sensors (OYO GEOSPACE MP25-350 10Hz) installed in boreholes PS1-N3 and PS1-S (see fig. 2).

Hydrophone sensors have been chosen because of (1) the inundation of the boreholes with water and (2) the demonstration of the excellent sensitivity of the hydrophones (8 Volt/bar) and the relatively wide frequency band thereof (a laboratory-tested 10 to 1,500 Hz) during previous microseismic listening campaigns conducted by INERIS on other sites. The drawback of this solution is the lack of three-dimensional information on the received waves and the deficient measurement of the S-waves. Nevertheless, it appeared sufficient to us in light of the goals of this initial experiment.

The installation depths of the sensors were selected such that the listening device was as close and centered as possible relative to the injection point.

The sensor arrays are connected to two signal amplification boxes (AMPSONG-AMG) located at the head of the borehole and having a gain that is adjustable from 0 to 60 dB.

The amplified signals then travel, via a shielded transmission cable, to an acquisition cabinet (Portable Acquisition Unit) installed in the "bypass" gallery. This box performs the filtering and digital acquisition of the signals, via the SYTMIS® software suite.

The sampling frequency was parameterized at 16 kHz throughout the entire experiment so as to enable the accurate digitization of the signals up to the upper cutoff frequency of the sensors (~1,500 Hz).

3.2. Tests of proper operation

Several tests have been conducted to check the proper operation of the microseismic instrumentation.

First the proper operation of the sensors was verified by generating signals from the CARBOLAB gallery by means of hammer blows. The response from the sensors proved to be compliant.

Secondly, an analysis of the electrical background noise shows that it is relatively significant, approximately 20 mV, or more than 10 times the noise level typically recorded with this type of acquisition device (a few mV at most). The noise is present on all of the channels and interferes with the signal from the hydrophones. The spectral analysis of this noise clearly indicates a dominant frequency of 50 Hz as well as its harmonics (100, 150, 200 Hz…). It emerged that the recorded noise is in all likelihood coming from electrical cables having a large cross-section that are present in the mine galleries. This noise significantly affected the sensitivity of our hydrophonic listening device.

Finally, calibration shots run from borehole GP1-S were used to verify the proper operation of our device and estimate the propagation speeds of the P-waves in the studied area. The mean propagation speed of the P-waves between boreholes GP1-S and PS1-S is approximately 5,000 m/s. The mean propagation speed of the P-waves between boreholes GP1-S and PS1-N3 is approximately 4,300 m/s. These speeds are consistent with the speeds generally recorded in this type of medium. The difference in speed can be explained by the different nature of the crossed terrains (in the case of borehole PS1-N3, the rays pass through the coal seam, where the propagation speeds are known to be slower).

3.3. Monitoring of the injection test

Baseline monitoring performed before start of injection led to the observation of intense and continuous activity at the two instrumented boreholes. This activity seems to be related to water flows in the boreholes and makes it difficult, in practice, to detect signals related to other sources (e.g. mechanical ruptures in the rock). This “hydroacoustic background noise” impaired the sensitivity of the listening device.

The hydrophone listening device was operational throughout the entire duration of the experiment. Unfortunately, the breakdown of a piece of equipment (not detected due to the impossibility of remote management) resulted in the loss of the data recorded during the first part of the injection: from 3 July 2013 to 24 July 2013. We therefore only have listening data as of 25 July 2013.

About 300 events per day (frequency > 70 Hz, amplitude > 0.1 V) have been detected. We did not detect signals other than those related to the “hydroacoustic background noise”. The lack of detection of any activity exogenous to that background noise may indicate that (1) the CO_2 injection did not generate any activity, in particular micro-ruptures, or (2) that activity was too weak to be able to be detected by our listening device in light of the low sensitivity thereof, which is related to the continuous “hydroacoustic background noise”, or (3) that activity occurred at the beginning of the injection (during the first days), a period for which we do not have data. In all cases, it is possible for us to affirm that during our study period (after 25 July), we did not record high-energy microseismic signals (of the micro-rupture type).

3.4. Leakage detection

Figure 3 shows the variations in the daily number of events as a function of the injection pressure. There is an obvious correlation between the two series of data.

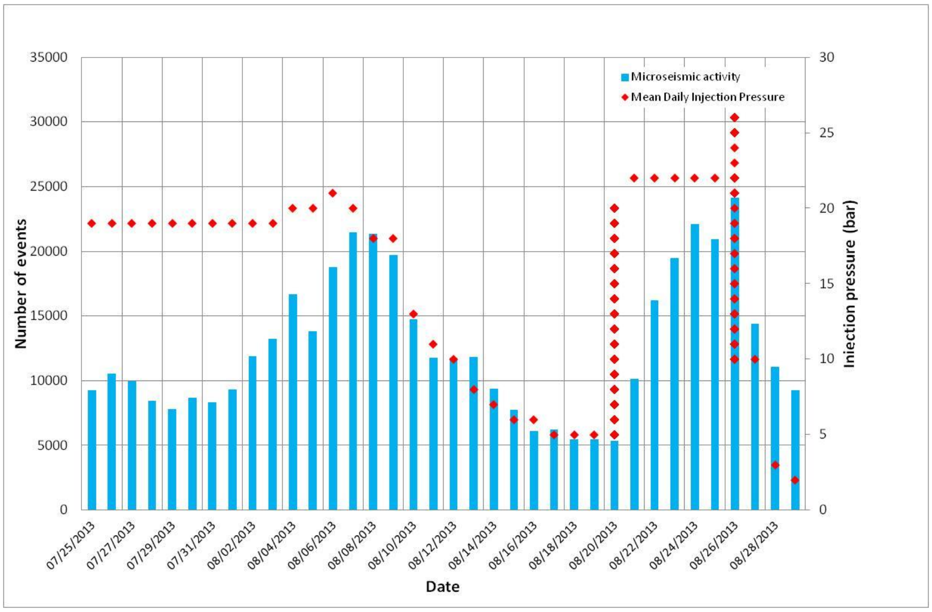

Fig. 3. Comparison of the injection pressure and the number of microseismic events recorded (no filtering in frequency, amplitude > 0.5 V; about 10,000 events per day).

It can be deduced therefrom that injecting CO_2 into the coal seam affected the intensity of the hydroacoustic noise. This observation confirms the first hypothesis regarding the origin of that noise, namely that the latter is in all likelihood related to the water flows in the boreholes. The correlation observed with the CO_2 injection can then be interpreted as the signature of the fact that the injected CO_2 was leaking outside the coal seam and reached the monitoring boreholes located approximately 15 meters from the seam on either side thereof.

4. Geochemical monitoring

Concerning the geochemical monitoring, INERIS was in charge to settle (1) continuous gas monitoring in boreholes dedicated to geochemical monitoring, and (2) gas flux measurements on the floor and on the walls of the CARBOLAB gallery to detect any gas influx from the rock inside the gallery. These systems have been settled to determine baseline before injection starts, and to monitor the injection and the post-injection phase.

4.1. Geochemical monitoring instrumentation

BRGM and INERIS have equipped boreholes GC1 and GC2-2 for geochemical monitoring (see fig. 2). These two boreholes were drilled “parallel” to the injection borehole and end at about 6 meters from the injection point. Both boreholes were equipped with gas sampling lines and 2 packers that delimit one monitoring chamber in surrounding rocks (between packers 1 and 2; see fig. 4) and another monitoring chamber in coal (below packer 1). Unfortunately, because GC2-2 was filled with water, it was not possible to perform gas measurements in this borehole. Continuous gas monitoring was only performed in borehole GC1 and included: gas pressure, gas temperature and CO_2 and CH_4 concentrations in gas phase. Gas pressure in the gallery was also monitored. INERIS was in charge of the continuous gas monitoring. BRGM performed water monitoring in both boreholes (for further details, refer to [2]).

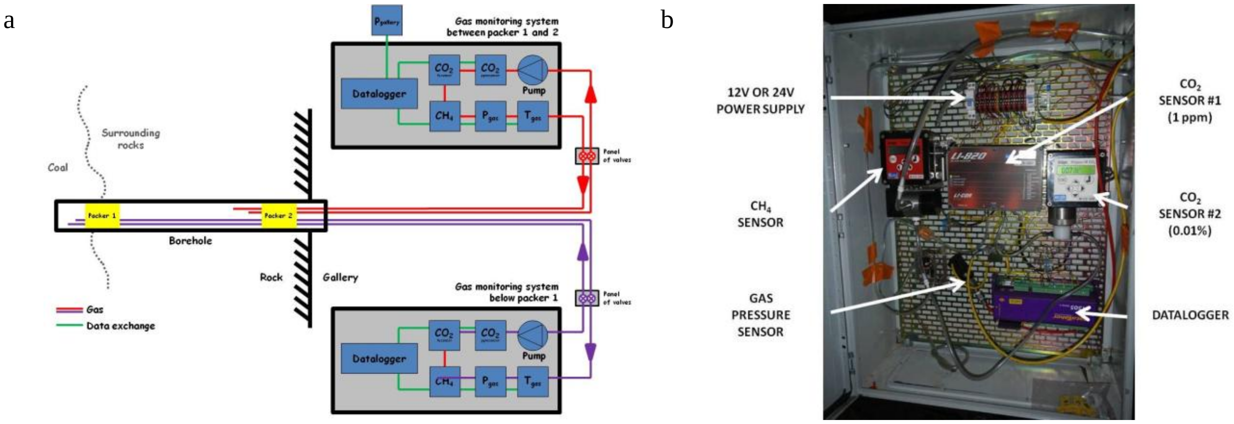

Fig. 4. Continuous gas monitoring: (a) diagram of a gas monitoring system; (b) photography of a gas monitoring system.

4.2. Test of proper operation

A detection test has been realized below packer 1 in borehole GC1: a small quantity of CO_2 (~5 Nl) has been intentionally injected in the monitoring chamber in coal to check if the gas monitoring system would detect the CO_2 breakthrough in coal from injection. Result of the test confirms that the system was working fine and that travel time in the gas sampling line was about 90 seconds.

4.3. Monitoring of the injection test

Baseline monitoring revealed that gas concentrations in coal (below packer 1) were about 5% (volume) of CO_2 and 95% of CH_4. In surrounding rocks (between packer 1 and 2), concentrations were about 10% of CO_2 and 90% of CH_4.

As injection started on 3 July 2013, CO_2 concentration between packer 1 and packer 2 in borehole GC1 increased from ~10 % to 97% and CH_4 concentration decreased from ~90% to 3% (fig. 5). It appears that the CO_2 injected in coal was migrating from the injection point in coal to the surrounding rocks through at least one preferential pathway crossed by borehole GC1. In other words: a certain amount of injected gas was leaking outside the coal seam. The leak was monitored all along the injection. After injection was stopped on 10 September 2013, CO_2 concentration decreased down to ~1% and CH_4 concentration decreased down to 0% between packer 1 and packer 2 in borehole GC1.

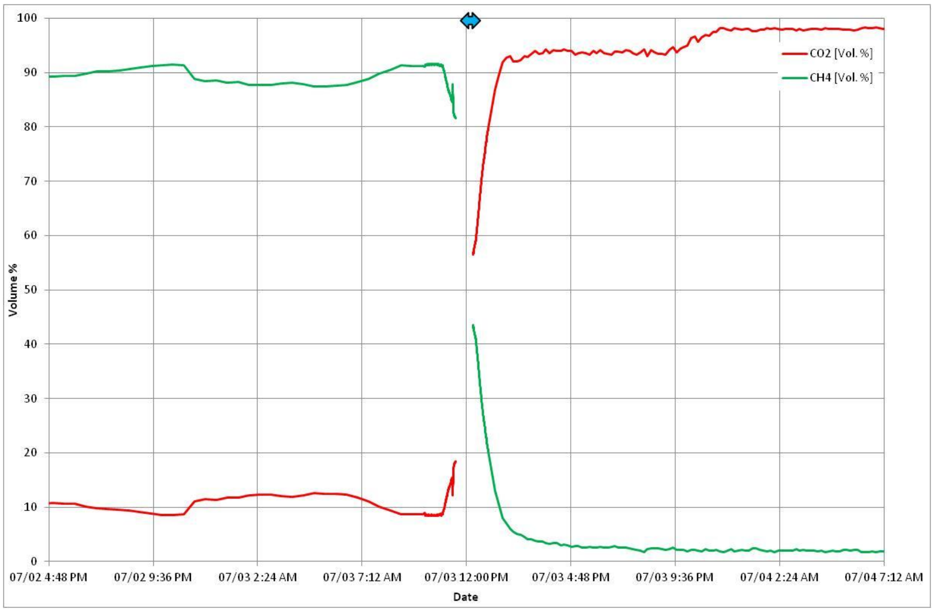

Fig. 5. Gas monitoring between packer 1 and packer 2 in borehole GC1 on 3 July 2013. Light blue arrow indicates a loss of data.

During injection test, no modification of CO_2 and CH_4 concentrations has been monitored below packer 1. It means that no CO_2 breakthrough was monitored in coal.

4.4. Leakage estimation

Because the mine gallery acts like a local drain, leaks are supposed to backflow in the gallery. With the collaboration of AITEMIN, HUNOSA and BRGM, several gas flux measurements have been done using the INERIS accumulation chamber (European patent: EP 0 807 822 B1; fig. 6) on the floor of the gallery. CO_2 emissions from the rock to the gallery have been detected close to the head of the injection borehole. Several gas flux measurements have been performed in this area and showed that total leakage rate was between 19 and 37 Nl_{CO2}/h in July 2013 and rose between 125.5 and 253.5 Nl_{CO2}/h in early September 2013. It means that 15% to 65% of the injected gas was leaking in the gallery.

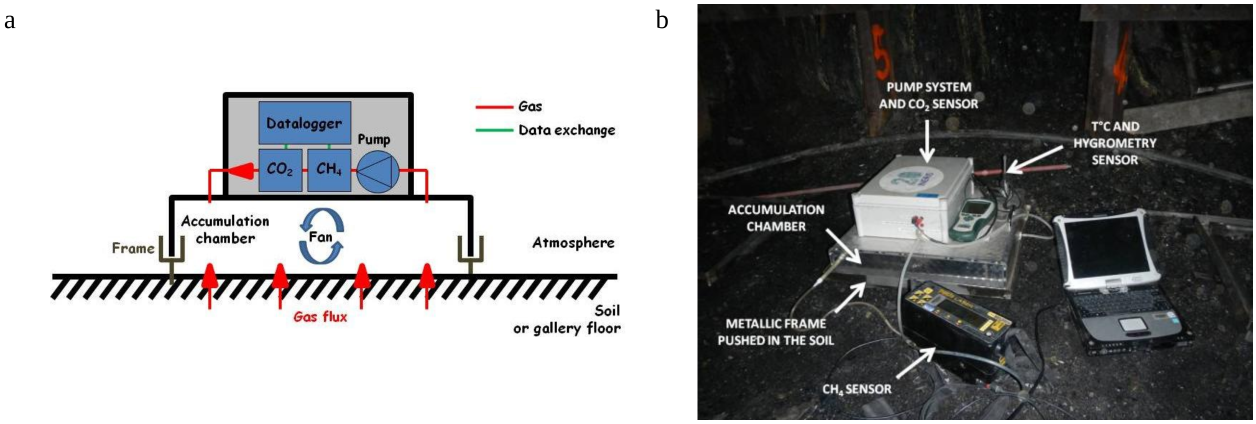

Fig. 6. Gas flux measurement on gallery floor: (a) diagram of gas flux measurement system; (b) photography of gas flux measurement system.

Taking into account the quantity of gas that was injected and the leakage estimation, the quantity of CO_2 that was really injected in the coal seam has been estimated to 120 kg. This quantity was smaller than expected at the beginning of the project and so, the geochemical monitoring in coal was not designed adequately. Gas migration was not monitored in coal because the quantity of CO_2 really injected in coal created a gas “plume” whose radius (estimated to 1 to 1.5 m) was smaller than the distance between the injection point and the monitoring chambers (~6 m). That’s why no CO_2 breakthrough was monitoring in coal during the injection test.

5. Conclusion

INERIS has monitored a CO_2 injection test performed in a coal seam of a Spanish mine. INERIS performed passive seismic monitoring and gas monitoring prior, during and after the injection test. Both data from passive seismic monitoring and geochemical monitoring revealed that leakage occurred during the injection test.

Due to leakage, gas migration was not monitored in coal because the quantity of CO_2 really injected in coal created a gas “plume” whose radius was smaller than initially expected. Thus, it was not possible to monitor the CO_2 breakthrough in coal during the injection test, because monitoring plan was not setup adequately.

Here, passive seismic monitoring and continuous gas monitoring proved to be valuable tools to observe gas migration and the behaviour of the rock during the injection test. They also helped us to understand the discrepancies between observations and predictions. The results we obtained will help us to draw recommendations and to design future in-situ injection operations in coal, as well as CO_2-enhanced coal bed methane recovery operations.

Acknowledgements

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