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Lessons Learned from Practical Application of Geochemical Monitoring Methodology to CO_2 Storage Site: Specific Case of Claye-Souilly project, Paris Basin, France

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Abstract

This paper presents the lessons learned from practical application of CO_2 storage site monitoring methodology developed to address geochemical aspects of future CO_2 storage site. It covers a detailed description of the methodology and tools applied for the extremely complex industrial site that main technical challenge is the presence of the multi sources of CO_2 at the surface and in the soil.
On the basis of previous research programs conducted on natural CO_2 storage sites, a specific geochemical monitoring program was developed that combine both a localized and continuous geochemical monitoring.
The paper focuses on the surface gases monitoring techniques spread on specific site to quantify CO_2 flux and concentration at different levels from soil-atmosphere-interface : -1m to +1m. The geochemical monitoring was based on the combined use of conventional accumulation chambers and dynamic flow chambers systems equipped with high resolution IR sensors, Fourier Transform infrared sensors equipped with specific gas cell and a CO_2 mobile infrared sensor. This first step has lead to the location and discrimination of CO_2 sources and the analysis of the carbon cycle involving the influence of anthropogenic events and of the natural seasonal variations. Combined methodology matrix for a geochemical surface survey adapted to CO_2 storage in Paris basin depth saline aquifer is argued and the measurement results are discussed. ^{13}C isotopic analyses to insure gas traceability have been also applied. Results are not shown in the paper. On the basis of such combined surface and sub-surface gas measurements, seasonal variations of the natural CO_2 cycle were identified. As results, sensitivity and variability were considered to suggest the CO_2 warning levels adapted to detect CO_2 abnormal emissions on the surface.
Finally, advanced complementary technologies for both soil and atmospheric gas investigations are also detailled as a part of the survey strategy. For soil gases, a specific completion in a shallow well has been developped to perform the continuous acquisition of CO_2 concentrations at a depth of 10 m. For atmospheric gases, a scanning imaging infrared remote sensing system was tested to support atmospheric dynamic survey strategy.
This site study applied to Claye Souilly waste disposal represents the real "hand on" experience and could be considered as a valuable experience to improve part of the geochemical monitoring program of CO_2 storage site.

Introduction

Considering the objectives of the greenhouse gas emissions emission reduction, Veolia Environnement began in 2005 a research program on the capture and storage of CO_2 with the aim of improving knowledge and developing site specific solutions to suit the differing sizes and types of its client's facilities. Managing roughly 100,000 sites throughout the world, including combustion facilities and non-hazardous waste landfills, Veolia Environment Research & Development launched an assessment of a geological storage experiment to identify the technological and economical validity of CCS implementation.

Waste disposal of Claye-Souilly

A non-hazardous waste landfill in the Île-de-France region was identified for a possible CCS pilot project in 2008. With close to 2 million tons of waste landfilled annually, these facilities are one of the most important non-hazardous waste landfills in Europe. The waste is compacted in shallow horizontal layers in waste cells. Each cell is equipped with waterproofing, drainage for the liquids (leachates) that percolate through the waste, and a landfill gas recovery system. Residual wastes contain materials that are for the most part biodegradable. When they decompose in an oxygen free environment, they give off a biogas that is mainly composed of CO_2 and methane, a more harmful greenhouse gas than carbon dioxide. This biogas, collected in the first 20 m of the shallow layers of the waste cells, presents an important challenge for the elaboration of the monitoring program.
Veolia goes beyond the regulations requiring collection of this biogas and generates an increasing amount of electricity from it. Claye-Souilly site has a combined-cycle gas turbine, boiler and steam turbine that recover 17,000 Nm^3 per hour of landfill gas used to supply the energy production units. In total, the biogas combustion plant generates about 0.1 Mt/y of CO_2.

CCS project background
On the basis of a preliminary site selection study, detailed studies were carried out to confirm that the selected site was adequate to store 100 000 t of CO_2 per year.
The CO_2 is produced from a waste-supplied thermal power plant and could be captured by the special units. Different scenarios were studied to assess the possibility to inject the supercritical CO_2 into a saline aquifer in targeted Triassic sandstones, located at a depth of more than 2000 m.
The geological preliminary studies were carried out in order to determine the injectivity, the storage capacity and the cap rock integrity to insure the technical feasibility of CO_2 storage in the targeted rock Triassic formation.
The results of the seismic Claye Souilly site, reprocessing of 330 km of existing profiles, are described in [1]. Each step of the construction of the geological model based on the data of the Ile de Gord field (drilling report, reservoir maps, well logs …) is presented in a separate paper "Technical challenges in characterization of future CO_2 storage site in a deep saline aquifer in the Paris basin. Lessons learned from practical application of site selection methodology " [2]. Once Claye Souilly site was identified for potential CO_2 storage, different preliminary studies were launched to select suitable monitoring program.

The quantitative establishment of this initial baseline is an imperative of any CO_2 storage site to be able to distinguish the "conventional fluctuations" from any abnormal CO_2 emission, as future CCS projects should provide the demonstration of the safety and the absence of leakage at all levels [3], [4].

This paper is focused on the monitoring program in a very challenging environment and provides the results of the appropriate geochemical monitoring baseline that monitors the seasonal fluctuation of the gas flux/concentrations of landfill CO_2. Providing the environmentally effective and "climate friendly" waste management solutions is a challenge that monitoring program can solve by controlling the impact of each source of greenhouse gas.

Specificities of Claye-Souilly site

To defin a monitoring program on the basis of the site's characteristics, three main characteristics and associated technical challenges were considered:

- Biogas at shallow depth

The average landfill gas is made of: 50% methane, 35% carbon dioxide, 14% nitrogen and 1% oxygen. The gas occupies the first 20 m of the shallow layers close to the surface and represents an important challenge for the elaboration of the monitoring program by comparison to other CCS projects.

- Urban area

A particular attention was required on the monitoring program as the Claye-Souilly site is located in a dense urban area only 10 km from the biggest Paris airport (Charles de Gaulle) with a high way that goes along the industrial site and less then 550 m from the high speed train, and near the medium size city of Claye-Souilly.

- Neighboring operational oil field

A mature oil field is located 1.5 km from the Claye Souilly landfill and more then 21 oil wells were drilled in early 90's.

Taking into account the specificities of the site and on the basis of previous monitoring results on natural CO_2 production site [4, 5, 6 and 7] and existing French research program [8], the main objectives of the future geochemical monitoring is to control, test, optimize and validate the various types of technologies or combinations of technologies, appropriate to guarantee the safety of the CO_2 storage site at all levels where storage could impact the environment. At the surface, the initial goal was to establish a network of surveillance points and the alert thresholds with regard to the natural emission, impact and variability of CO_2 from biogas. The additional important information, expected form the baseline measurements was the assessment of the seasonal fluctuation of CO_2 near the location on the possible injection well.

Geochemical monitoring techniques applied to surface gases

Following monitoring tools and technologies were used for the baseline geochemical monitoring:

Conventional accumulation chambers method and CO_2 mobile infrared sensor

Previously measurements have shown the necessity of associating conventional accumulation chambers and mobile IR sensor (MSR PTC 82-1160) for surface CO_2 mapping.

This whole portable device is supported by a specific mobile device dedicated to the immediate measurement of the surface atmospheric CO_2 (+1m), the temperature and the atmospheric moisture content. The precision of this sensor to CO_2 is of +/-30 ppm in a range of concentrations going from 30 to 9000 ppm.

Concerning the measurements of CO_2 flux at the soil/atmosphere interface, the measurements are made by accumulation chambers (INERIS CARE method) connected to high-resolution sensors [9], [10]. These measurements are subordinated to the continuous recording of the conventional meteorological parameters (temperature, atmospheric pressure, wind directions, moisture…).

With using measuring devices, the range of flux measurements spreads out from 0.05 to 4000 $cm^3.min^{-1}.m^{-2}$. The threshold of detection for CO_2 is located between 0.01 and 0.05 $cm^3.min^{-1}.m^{-2}$, according to the local conditions of the site. This establishes a very low limit of detectability of CO_2 flux that is below the usual level of emissions of a biogenic origin as observed in Europe [10], [11].

Based of the detailed topographical characteristics of the site and the waste cells locations, the specific measurement network was proposed and each landmark, associated to the measurement point has been geo-referenced to ensure the Claye Souilly repeatability of each measurement campaign.

The measurement network applied on Claye Souilly site is presented figure 1. The position of 162 measurement points distributed on about ten square km have been defined as follow:

- 50 points on a limited area around the position of the possible CO_2 injection well, located at the North West part of the site.
- 100 points distributed on the different waste cells
- 10 points distributed on a natural soil outside of the Claye-Souilly landfill site.
- 2 points located on geological faults.

It must be remembered that gas flux and concentration measurements can be strongly influenced by the interaction with biogas produced on Clay Souilly site.

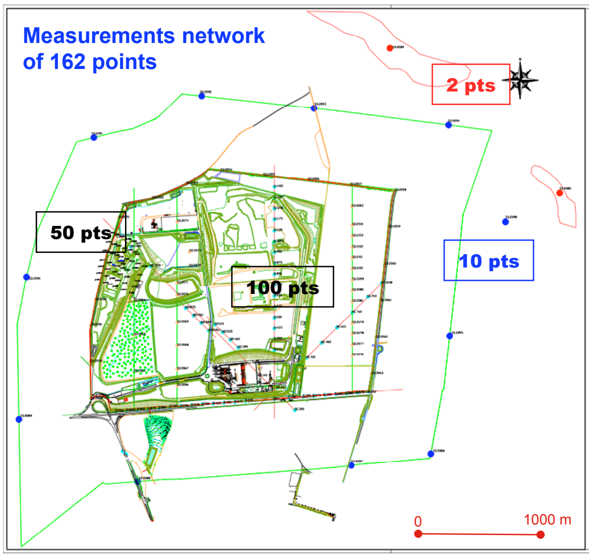

Figure 1: Experimental network (162 points) for gas measurements on Claye-Souilly site.

Sub-surface gas measurement results

Biogas:

Gas from collector before the gas plant has been sampled. Average chemical analysis of biogas for October 2009 is given in table 1.

Table 1: Average chemical analysis of biogas

	CO_2	CH_4	N_2	O_2	Propane	n-Butane	i-Butane	Propene
Major (%vol)	34.9	42.7	19.4	3.1				
Minor (vpm)					4.2	5.5	3.3	8.4

Main gases are CH_4 and CO_2 with some complementary minor organic gases. Some small variations can be noticed as a function of the type of the waste cell. These variations more strongly affect minor gas content.

CO_2 fluxes and atmospheric CO_2 concentrations at the soil/air interface

The first measurements on Claye-Souilly site were performed during one seasonal period (October 2009, March 2010 and September 2010) in order to appreciate seasonal variations of CO_2 flux and concentration levels on the site of Claye-Souilly before any injection operations. They were firstly focused on surface (0 to +1m) and were relative to CO_2 flux (0m) and surface atmospheric concentration determination (+1m).

A 2D/3D illustration of typical map of CO_2 concentration and flux obtained on Claye-Souilly site are given on figure. This type of CO_2 fingerprints was used to identify any additional CO_2 contamination and will serve as basic tool for the understanding of surface gas exchanges. This approach can be also extended to annex gases including artificial tracers. Increase of the measurement point network simulates the monitoring strategy around an injection area. This kind of 2D/3D map will constitute the first step of gas baseline quantitative definition. This will also constitute specific tools for understanding the functioning of the Claye Souilly Site and to identify the CO_2 fluctuation levels before any injection.

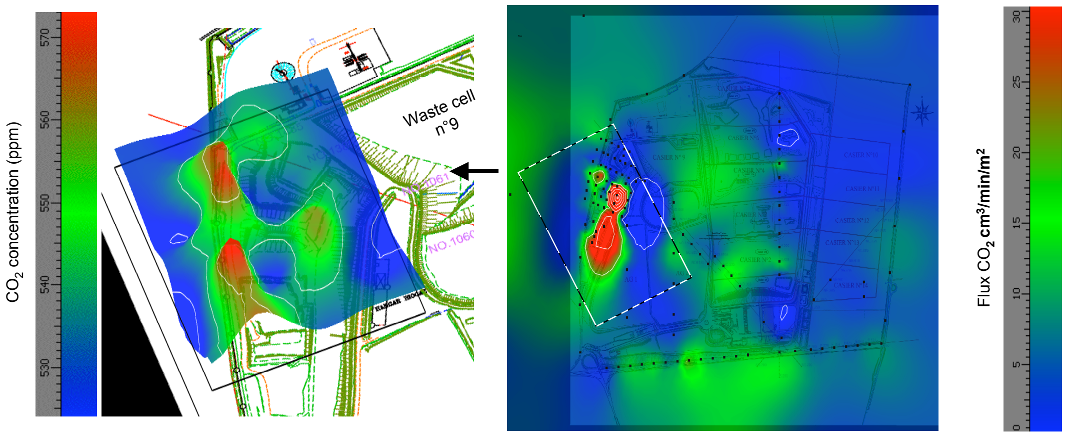

Figure 2: Typical 2D/3D interpolated map of CO_2 surface monitoring (October 2010):
Right part - CO_2 fluxes in $cm^3.min^{-1}.m^{-2}$ measured at the air/soil interface
Left part - Atmospheric CO_2 concentration in ppm measured at +1m.
(Interpolation process is made using ©GOCAD software)

The campaign of October 2010 has allowed distinguishing three spots of emission with CO_2 flux between around 30 $cm^3.min^{-1}.m^{-2}$ (figure 2). These three spots are more or less superimposed to the maximum of atmospheric CO_2 concentration (> 560 ppm). They can be assigned to gas leakages from old waste cells non-equipped with liners at the time of waste deposition. The highest CO_2 concentrations are located in topographic depressions. High CO_2 fluxes around 15 $cm^3.min^{-1}.m^{-2}$ are detected in the central part of the site and on an E-W line all along the highway. Such high flux is explained by the superimposition of CO_2 coming from a damaged pipe of water drainage and of CO_2 coming from traffic.

This explains that gases are present in the soil by diffusion from neighboring waste cells and can be exchanged with the atmosphere. Such 2D/3D maps strongly argue for the existence of abnormal emissive areas in the north-west segment of the Claye-Souilly site.

These observations have been confirmed by soil gas continuous measurements at –10m depth in the North West part of the site (50m north-north-West side from the position of the CO_2 injection well) and by infrared remote atmospheric measurements. CO_2 and CH_4 soil concentrations have been determinated varying from 30 to 36% and from 35 to 47% respectively (measurements not shown from June to December 2010). This definitively concludes that biogas is still present in the soil at this north-west part of the Claye-Souilly site and is partly exchanged with the atmosphere. However, the gas concentrations in surface air stay very low and do not present a danger for human health or safety.

Seasonal evolution of the average CO_2 fluxes and concentrations

Three series of measurements performed between October 2009 and September 2010 have shown that average CO_2 fluxes at the Claye Souilly site vary between 5 and 15 $cm^3.min^{-1}.m^{-2}$ (figure 3 left) and CO_2 concentration in surface air vary between 420 and 540 ppm (figure 3 right).

Average natural CO_2 flux vary in France between 2 and 8 $cm^3.min^{-1}.m^{-2}$, according to the season (Figure 4), and normal CO_2 concentration in the atmosphere is situated between 390 and 500 ppm. [12] [13].

Despite some anomalous emission zones indicated in figure 2, the figure 3 shows clearly that average CO_2 fluxes and atmospheric concentrations in studied Claye Souilly site are similar to reference values in natural environment. These results show the very good efficiency of the biogas collection in most parts of the site.

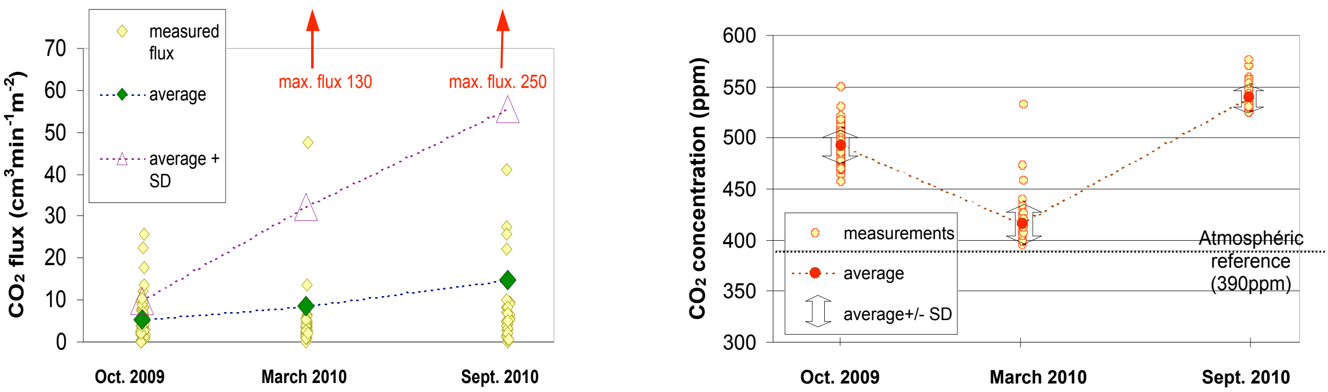

Figure 3: Seasonal variation of the average CO_2 fluxes (left) and concentrations (right) on the Claye-Souilly site.

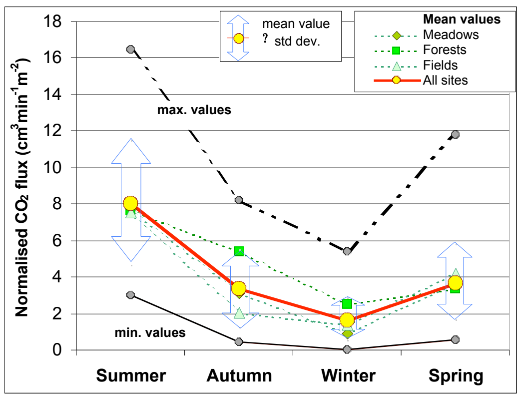

Figure 4: Evolution of the average fluxes in France according to the type of ground and the season. Measurements by INERIS accumulation chamber on the 2007-2009 period.

Discussion

On the base of our results obtained on the Claye-Souilly site and focused in the possible CO_2 injection well area, tables 2 and 3 collect the average values (Ave) of each campaign as well as the standard deviation (**σ**) for CO_2 flux and concentration respectively. The values of threshold of vigilance (Tv) for every campaign are indicated as well as the global average standard deviation. The threshold of vigilance is defined as the level from which the flux or concentration of CO_2 is judged acceptable range of variability : Tv = (Max - Ave **) / σ**.

Table 2: Threshold of vigilance for CO_2 fluxes in the area of the CO_2 injection well of the Claye-Souilly site.

Campaign	Average Ave ($cm^3.min^{-1}.m^{-2}$)	Standard deviation **σ** ($cm^3.min^{-1}.m^{-2}$)	Concentration Min-max ($cm^3.min^{-1}.m^{-2}$)	Threshold of vigilance Tv ($cm^3.min^{-1}.m^{-2}$)
Oct. 2009	5,3	4.4	0,0 - 25,8	Tv = Ave + 4,6**σ**
March 2010	8,6	23,4	0,7 - 129	Tv = Ave + 5,1**σ**
Sept. 2010	14,8	40,6	0,0 - 253	Tv = Ave + 5,9**σ**

Table 3: Threshold of vigilance for CO_2 concentration in the area of the CO_2 injection well of the Claye-Souilly site.

Campaign	Average Ave (ppm)	Standard deviation **σ** (ppm)	Concentration Min-max (ppm)	Threshold of vigilance Tv (ppm)
Oct. 2009	492	17,5	460-554	Tv = Ave + 3,6**σ**
March 2010	416	20,8	390-540	Tv = Ave + 6**σ**
Sept. 2010	539	13	535-573	Tv = Ave +2,6**σ**

The baseline measurements indicate that the average levels of CO_2 fluxes and concentrations (Figure 3) on the whole Claye Soully site, except for points of evidences of biogas leakage, are close to the average background level of flux (Figure 4) and concentration [12], [13] in similar climatic areas.
The definition of "threshold of vigilance" and of "threshold of alert" needed for the operator to have the tangible indicator of the site monitoring program still remains, at this stage of the study, a difficult notion to define and to quantify because of four fundamental reasons:
- biogas leakages can be superimposed to natural CO_2 flux from soil, then, the variability from a point to another of the railing, for the same seasonal period, can reach six times the standard deviation,
- the CO_2 flux and concentrations in deeper levels (from 400 to 2500 m depth) are unknown,
- The measurement campaigns did not allow covering more than one seasonal cycle,
- At the surface, the variability between wintry / autumnal season and summer season is important,

By consequence, thresholds of vigilance determined in tables 2 and 3 cannot be used for an efficient survey of such a site.

Considering the complex area of the Claye Souilly site, we can recommend two specific improvements for the geochemical survey in such environment:

- creation of an adapted network of points of reference for the measurements at the surface and sub surface
- development of advanced complementary technologies for both soil and atmospheric gas investigations

An adapted network of points of reference for the measurements at the surface and sub surface is proposed (figure 5) in order to take into account the following observations:

- Strong emissions of CO_2 and CH_4 and in the North West part of the site,
- Existence of points of strong CH_4 emissions,
- Probability of emergence of gas through faults in the North-East part of the site,
- Necessity to increase the meshing at the level of the potential injection well,

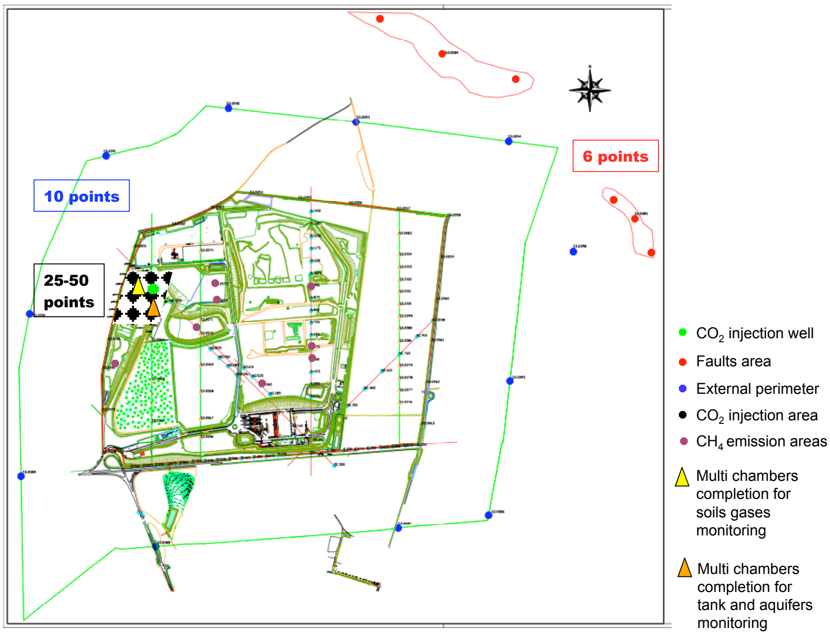

Figure 5: First matrix of location of the reference measurement points for a geochemical survey of Claye Souilly site.

This new strategy is based on 75 measurement points distributed as follows:

- 25 - 50 points of surveillance in surface and sub surface in perimeter restricted around the well of injection
- 7 reference points of surveillance at the surface and sub surface located on zones of potential CH_4 emission
- 6 specific points of surveillance at the surface and sub surface at the level of the outcropped faults in Northeast region
- 10 points of reference of surveillance in surface and sub surface at the level of the surrounding ecosphere of the Claye Souilly site.

New strategies are suggested for interpreting data, with the necessity of defining thresholds of vigilance by season, and establishing specific local thresholds in every point of observation.

The advanced complementary technologies for both soil and atmospheric gas investigations are composed of continuous gas recording for in situ measurements in wells and advanced atmospheric gases measurements, using a scanning imaging infrared remote sensing system.

The geochemical platform for continuous gas measurements in boreholes.

The constant optimization of the continuous measurements of the gases from an instrumented drilling is a regular activity of SOLEXPERTS Company. In partnership with the Université de Lorraine, a geochemical platform for continuous soil gases measurements was set up. The figure 6 shows the principle of the gas continuous measurement module constituted by three parts: 1) the completion, 2) the circulation gas system and 3) the Fourier transform infrared sensor.

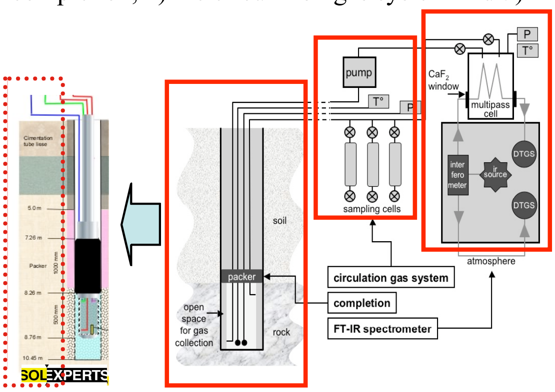

Figure 6: Technical details of the platform for continuous geochemical monitoring of gases that should be implemented on the Claye Souilly site.

The completion is equipped with a chamber isolated of the rest of the column by a packer (Figure 6) and allowing gas collection and circulation towards the IR sensor. The monitoring borehole temperature, gas pressure and pumping flux are also monitored. The system is connected to a circulation gas module with numerous removing sampling cells. The monitoring borehole is located in the North West part of the site, near to the possible location of the CO_2 injection well.
The infrared sensor (Bruker, Alpha spectrometer single compartment) is equipped with a gas cell with a fixed 5 cm optical path. Spectra are recorded in transmission mode on the range 5500-500 cm^{-1} with a 1 cm^{-1} spectral resolution and a 2 zero filling. Each measurement is the average of 10 scans and is recorded each hour.
Calibration of IR sensor was acquired at Université de Lorraine laboratory using a procedure described in [12] and the following limits of sensitivity have been established:

- For CO_2:
  +/-8 % for a concentration from 150 ppm to 294 000 ppm in total ranges of pressure from 950 to 1050 mbar.
  +/-7 % for a concentration from 102 000 ppm to 330 000 ppm in ranges of total pressures from 950 to 1050 mbar.
- For CH_4
  +/-6 % for a concentration from 0 to 200 000 ppm to total ranges of pressure from 950 to 1050 to mbar.

The experimental protocol includes two interfaces of measurements (OPUS -Bruker Optics and GEOMONITOR-Solexperts) and a friendly interface of display (WEB DAVIS-Solexperts). The interface OPUS, is used for managing the parameters of the IR sensor and the measurement. Quantitative treatment of transmission IR spectra is made through a specific laboratory software [14], [15]. This will lead to the establishment of a specific tool to appreciate any abnormal deviation of the CO_2 concentration with regard to a standard state behavior.
It is proposed to implement two completions in two different boreholes:

- 1 multi chambers completion for the continuous monitoring of the reservoir and the deep aquifers (-2000 m)
- 1 multi chambers completion for the continuous monitoring of the ground and the superficial aquifers (-10 m)

The completion could allow to connect other sensors like Raman spectrometers, micro-GC or isotopic analyzers.

Atmospheric gas measurements.
Infrared emission remote technology is proposed to be used for atmospheric gas measurements. Remote sensing approach is based on the use of Fourier-transform infrared emission spectroscopy OPAG system (EM27 Bruker Optics). This will contribute to global control of the CO_2 and annex gases of the site. It allows an analysis of the composition of a gas mixture in long distance (0 to 5,000 m), in a volume of 0.1 to 125 km^3, and on a spectral range going from 600 to 5,000 cm^{-1}, with a 10 m spatial resolution at a distance of 1,000 m. Scan velocity can be better than 16 spectra per second.
The sensitivity for the CO_2 is better than 50 ppm.m (i.e. less than 1017 $molecules.cm^{-2}$) with a nearby relative error of 5-10 %. [16], [17] [18]. This type of remote sensing is also sensitive to annex gases such as CH_4, NOx, H_2S, H_2O, O_3, SF_6

Finally, the presence of the mature oil field near the Claye Souilly site and the presence of the different sources of soil gas demonstrate the advantages of the proposed methodology based of the spectral signature. In fact, the quantitative analysis of any particular gas could be done from the existing measurements. In particular, this work was performed for the methane and any other gases that should be monitored during the CO_2 injection phase of the project and can be appreciated like potential tracers of CO_2 linkage.

Conclusions

An appropriate monitoring program proving that CO_2 can be stored safely for a long time is a key factor in controlling long term storage efficiency of CCS projects. The main part of the geochemical monitoring should include the establishment of CO_2 flow baseline in 3 major compartments of any site: the geosphere, biosphere and atmosphere. Viability and public acceptance of any CCS project is strongly dependent on our capacity to establish a realistic quantitative baseline integrating natural and anthropogenic contributions in each compartment for the long period (some years?) before the first drop of the captured CO2 is injected to the targeted geological level.
CO_2 flux and concentration follow the natural carbon short cycle and depend on geographic location of CO_2 storage site and vary with time according to anthropogenic events and industrial units located nearby.

Special challenges of the Claye-Souilly site can classify this specific site as the “ worse case” for the monitoring environment. They can be summarized in 5 main following categories:

- Presence of Biogas (50% methane, 35% carbon dioxide, 14% nitrogen and 1% oxygen) at shallow depth,
- Multi CO_2 sources (airport, highway, vegetation, power plant, biogas),
- Operating Industrial site [1 km x 1 km] dedicated to waste repository with accessibility restrictions,
- Neighboring operational oil field,
- Urban area located near the industrial site

To propose an appropriate monitoring program, two years' work has allowed us to establish a complex monitoring program that addresses all aspects of geochemical monitoring. The undertaken work combined different well-known and advanced measurement technologies. The sampling strategy and the measurement grid of 162 points took into account geologic, industrial and biologic characteristics of the site. It allowd us to construct CO_2 flux and concentration maps. Chosen surface technical strategy was a combination of in-situ monitoring sensors at different levels:

- Biosphere (interface soil / air): CO_2 flux at 0 meter, chamber type devices like accumulation or dynamic chambers
- Atmosphere: CO_2 concentration at +1 meter above soil, near infrared sensor specific to CO_2 associated with complementary technologies:
    - Borehole with a completion equipped with a measurement chamber connected to an infrared Fourier transform optical sensor.
    - Remote infrared emission spectroscopy specific to atmospheric gas mapping from 0 to 5,000 meters.

Comparison of flux and concentration data allows us to define the CO_2 baseline level from -1 to +1m and its annual variability. Results show seasonal variations of flux and concentrations with local evidences of biogas leakage. On the basis of the presented variability of CO_2 flux and concentration baseline, the threshold of vigilance is ranged between 2.6 to 6.0 standard deviation of seasonal average value. These data are too spread to be used as useful thresholds of vigilance.

For this reason a new strategy is proposed, based on another network of measurement points, accompanied by atmospheric control using remote sensing Fourier-transform infrared emission spectroscopy, and the survey of two wells equipped with completions allowing transfer of gases towards gas sensors in surface for continuous gas analysis.
The proposed methodology could be redeployed for any CO_2 storage site where there are different CO_2 sources and industrial activity that influence seasonal CO_2 cycle. However, the threshold of vigilance should be adjusted for each specific storage site and points of measurement and should take into account local conditions.

The presence of any soil gas could influence the monitoring program and the presented methodology can be easily redeployed in the condition of the mature gas field where the presence of the different soil gases at the shallow level can greatly influence the results of the gas monitoring program.

Based of the combined results of the geological site characterization and surface monitoring program, the Claye Souilly site was identified as appropriate only for the small size pilot of CO_2 injection and storage. The main technical reason for this conclusion was the proximity to a neighboring oil field production presenting real well-integrity risks. The the presence of the major fault confirmed a potential risk for the industrial scale operations and the high level of the CO_2 natural emission around the possible area of the injection well. Based on this technical knowledge and taking into account the various financial and social factors, the decision was taken to not continue the construction of the CCS pilot storage. Despite the decision to stop the CCS project, the results of the monitoring program are valuable vouching for the continuation of the geochemical monitoring program, beyond the initial targeted objectives, in order to refine the modeling and monitor the soil gas of the one of the biggest non-hazardous waste landfills in the Europe.

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