Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 37 (2013) 4409 – 4419

Energy Procedia

GHGT-11

How to establish CO_2 flow/concentration warning levels based on the geochemical monitoring baseline: specific case of CO_2 storage at Claye-Souilly (Paris basin).

Jacques Pironon[a*], Philippe de Donato[a], Zbigniew Pokryszka[b], Odile Barrès[a], Natalia Quisel[c], Judith Sausse[a] , Noémie Taquet[a], Stéphane Thomas[c]

[a]*IMAGES group, Université de Lorraine-CNRS, Faculté des Sciences, BP 70239, 54506 Vandœuvre-lès-Nancy, France*
[b]*INERIS, Parc Technologique Alata, BP 2, F-60550 Verneuil-en-Halatte, France*
[c]*VEOLIA Environnement Recherche & Innovation, 10 rue J. Daguerre, 92500, Rueil-Malmaison, France, France*

Abstract

An appropriate monitoring program proving CO_2 can be stored safely for a long time is a key factor in controlling long term storage efficiency of CCS projects. A site in the Paris basin near Claye-Souilly area was identified for a future CCS pilot project. Baseline acquisition is deeply complex due to the presence of multi CO_2 sources (biogas, vehicles, industrial operations, natural sources). Campaigns of measurement have demonstrated the feasibility of such strategy to detect gas transfers from subsurface equipment. Survey of CO_2 storage is greatly affected by site activity and requires the development of efficient sensors in deep boreholes.

Keywords: CO_2 flow, CO_2 concentration; monitoring program; biogas; baseline; waste cell

* Corresponding author. Tel.: +33-383-684-732; fax: +33-383-684-701.
E-mail address: jacques.pironon@univ-lorraine.fr.

1. Introduction

Considering the objectives of the greenhouse gas 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

1876-6102
doi:10.1016/j.egypro.2013.06.346

experiment to identify the technological and economical validity of CCS implementation and define a baseline strategy.

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, the waste disposal of Claye-Souilly is 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.

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 [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.

2. Specificities of Claye-Souilly site

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

- Biogas at shallow depth in “modern” isolated waste cells

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.

- Ancient non equipped waste deposit below or near the shallow waste cells

Before the implementation of the biogas collection program, the Claye-Souilly site has stored similar wastes without confinement and gas collectors.

- 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 French airport (Paris-Charles de Gaulle) with a high way that goes along the industrial site and less than 550 m from the high speed train, and near the medium size city of Claye-Souilly.

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.

3. 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 (+1 m), 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 biogenic origin emissions as observed in Europe [10], [11].

Based on 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 fig. 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 fault area.

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

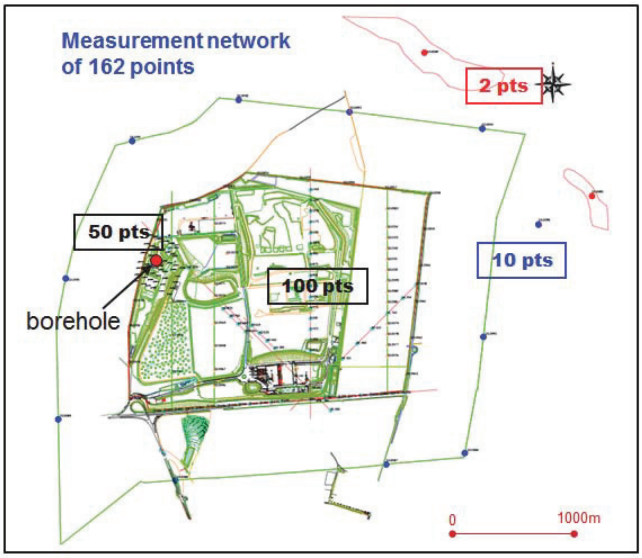

Fig.1: Claye-Souilly site with the location of the measurement network and the borehole

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 2 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.

The completion is equipped with a chamber isolated of the rest of the column by a packer (Fig. 2) and allowing gas collection and circulation towards the IR sensor. The inside borehole temperature, gas pressure and pumping flow rate 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 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.

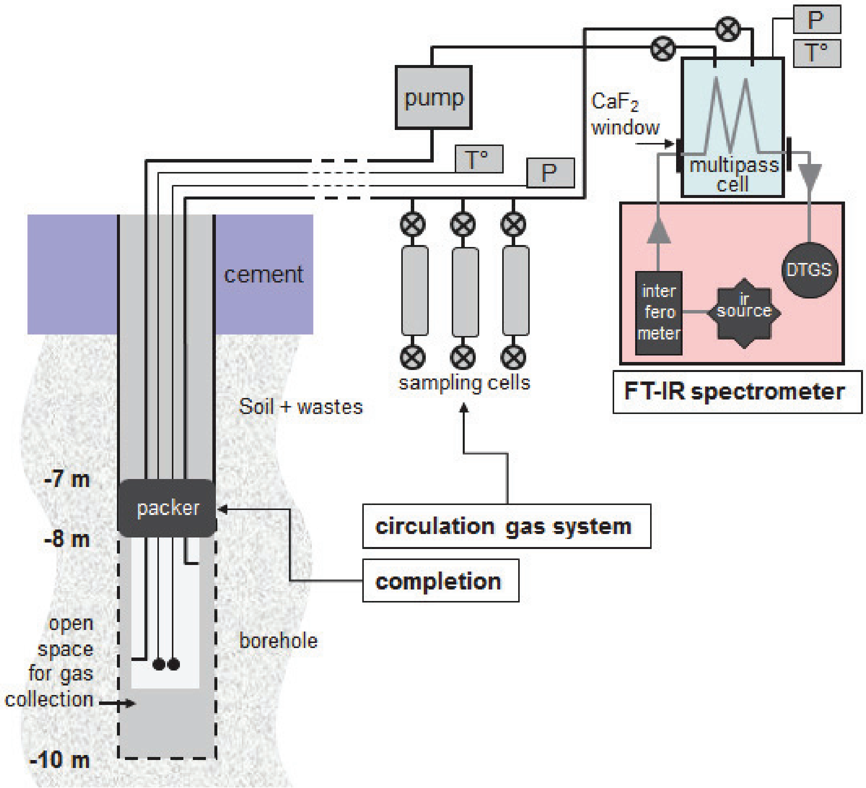

Fig. 2: The geochemical platform for continuous gas measurements in borehole

4. 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. 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, with a maximum variation of +/- 18% for major and +/- 110% for minor gas concentration. Biogas is methane dominated. The N_2/O_2 is O_2 depleted compared to the atmosphere.

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

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 cycle period (October 2009, March 2010 and September 2010) in order to appreciate climate 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 GOCAD™ interpolated map of CO_2 flux obtained on Claye-Souilly site in March and September 2010 (Fig. 3). Quick overview of fig. 3 indicates that biogas capture system developed on the site is effective with CO_2 fluxes variations included between 0 and 253 $cm^3.min^{-1}.m^{-2}$. This aspect will be developed further. Map of CO_2 flux of March 2010 and September 2010 show clear differences (high flux in the central part in March, and along the high way in the southern part in September) and some similarities (high flux at the eastern part of the area of measurements). Some of these variations are passing (central) and some other are persistent (eastern part). This approach can be also extended to annex gases including artificial tracers. This kind of 2D/3D interpolated map will constitute the first step of gas baseline quantitative definition allowing to estimate the temporality of gas transfer processes.

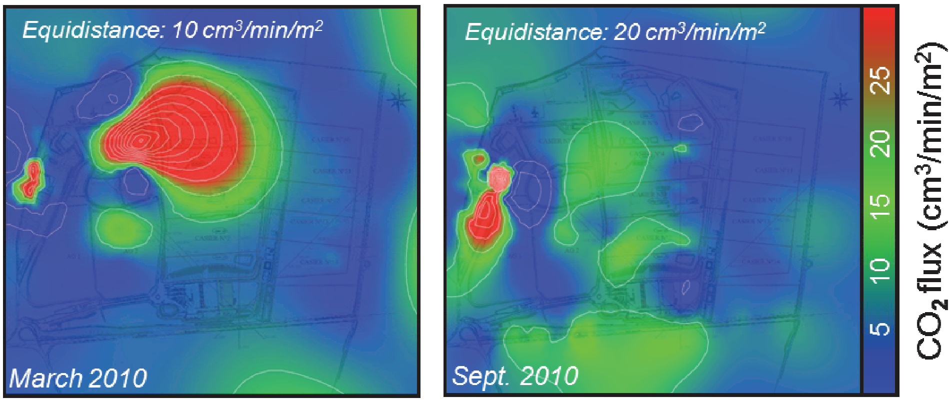

Fig. 3: Typical 2D/3D interpolated map of CO_2 fluxes measured at the air/soil interface of the landfill site of Claye-Souilly.

Fig. 4 shows two maps of CO_2 concentration obtained on North-West part of Claye-Souilly site at 1 m above the soil in March and September 2010. CO_2 concentrations vary from 390 to 580 ppm. Comparisons of concentration maps for March 2010 and September 2010 show that atmospheric concentration was different for the two periods of time.

The campaign of September 2010 has allowed distinguishing three spots of emission with CO_2 flux around 30 $cm^3.min^{-1}.m^{-2}$ (fig. 3). 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.

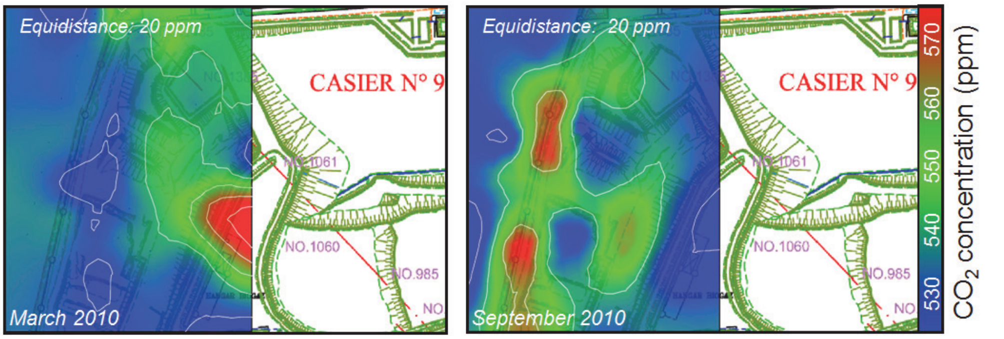

Fig. 4: Typical 2D/3D interpolated map of CO_2 concentrations measured at the air/soil interface of the landfill site of Claye-Souilly.

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.

Gas from the borehole

Previous CO_2 flux/concentration observations in the North West part of the site have been confirmed by soil gas continuous measurements at –10 m depth. CO_2 and CH_4 concentrations in the borehole are similar to those of the biogas. CH_4 concentration remains more or less constant during a period of measurement of 14 months. CO_2 concentration increased during the same period of time. These gases at 10 m depth have similar composition to biogas but show an increase of the CO_2/CH_4 ratio with time, probably due to changes in microbiological activity. High concentrations of CO_2 and CH_4 in soil have been also detected, mainly around the borehole and near the highway. No isotopic difference has been detected with $\delta^{13}CO_2$ varying between -12 and -16‰, $\delta C^{18}O_2$ between 28 and 33‰, and $\delta^{13}CH_4$ varying between -42 and -53‰. 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

Average natural CO_2 flux vary in France between 2 and 8 $cm^3.min^{-1}.m^{-2}$, according to the season, and normal CO_2 concentration in the atmosphere is situated between 390 and 500 ppm. [12] [13]. Figure 5 shows the variations of temperature, relative humidity and CO_2 concentration for the three campaigns of measurements. It appears that the dispersion of CO_2 concentration data is weak when temperature and relative humidity dispersion data were the weakest in September 2010. This explains the good correlation between CO_2 flux and CO_2 concentration only observed for the third campaign of measurements.

Despite some anomalous emission zones indicated in fig. 4 and 5, the data show 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.

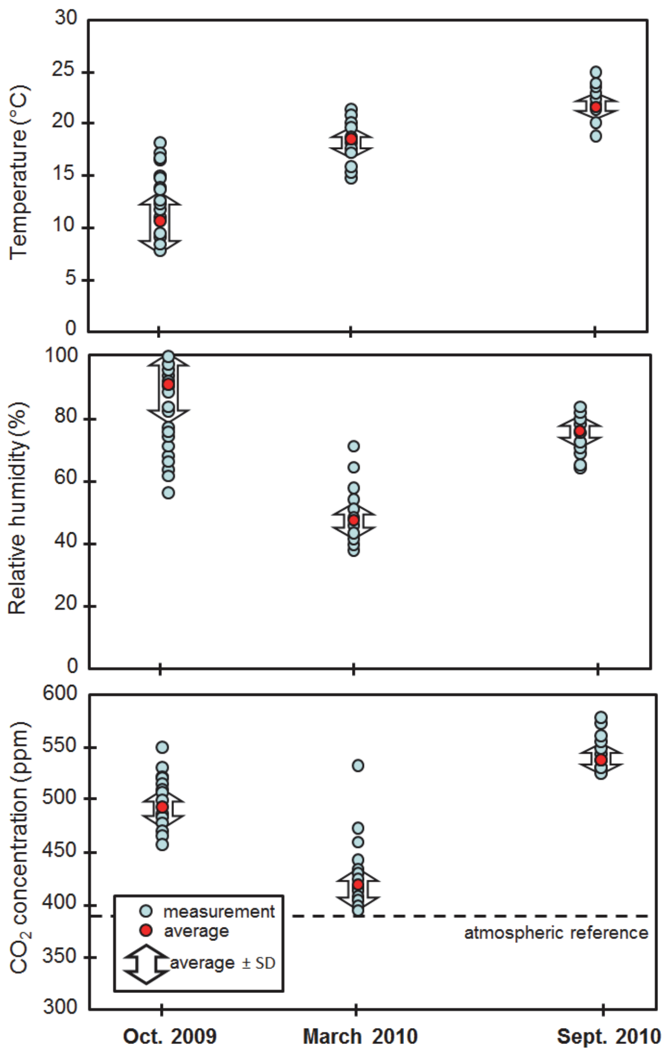

Fig. 5: Temperature, relative humidity and CO_2 concentration recorded for the three periods of measurements for the landfill site of Claye-Souilly.

5. Discussion and conclusion

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. For CO_2 flux, Tv can be written as follow:

$$Tv = (Max – Ave)/ \sigma.$$

For CO_2 concentration, it must be taken into account the standard CO_2 atmospheric content (390 ppm) and Tv becomes:

$$Tv = (Max – Ave)/ \sigma + 390$$

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 ($cm^3.min^{-1}.m^{-2}$)	Flux Min-max ($cm^3.min^{-1}.m^{-2}$)	Maximum range of variability Rv	Threshold of vigilance Tv_{flux} ($cm^3.min^{-1}.m^{-2}$)
Oct. 2009	5,3	4.4	0,0 - 25,8	4.6σ	25.5
March 2010	8,6	23,4	0,7 - 129	5.1σ	34.6
Sept. 2010	14,8	40,6	0,0 - 253	5.9σ	254.3

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)	Maximum range of variabilityRv	Threshold of vigilance $Tv_{concentration}$ (ppm)
Oct. 2009	492	17,5	460-554	3.6σ	607
March 2010	416	20,8	390-540	6σ	540
Sept. 2010	539	13	535-573	2.6σ	573

The baseline measurements indicate that the average levels of CO_2 fluxes and concentrations on the whole Claye-Souilly site, except for points of evidences of biogas contribution, are close to the average background level of flux and concentration [12], [13] in similar climatic areas. Moreover, weak gas exchanges between soil and atmosphere can be revealed by such monitoring approach.

On the base of the results of tables 2 and 3 and in spite of the existence of located areas of stronger emissivity, we can note that the seasonal variability combined with the industrial activity of the site, does not strongly disrupt the threshold of vigilance for CO_2 flux and concentration.

Nevertheless, 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:

- transfer of biogas from soil to atmosphere 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,
- presence of biogas is clearly detected down to 10 m depth in North-West area of the site,
- biogas composition at -10 m varies with time,
- the CO_2 flux and concentrations in deeper levels (from 10 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.

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

- Presence of biogas at shallow depth,
- Multi CO_2 sources (natural emission from soil, airport, highway, 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 allowed us to construct CO_2 flux and concentration maps. Chosen surface technical strategy was a combination of in-situ monitoring sensors at different levels. Nevertheless leakage detection in such site needs deeper monitoring systems below the biogas-rich zone. It can be proposed an additional monitoring borehole and great depth equipped with 1 multi chambers completion for the continuous monitoring of the intermediate aquifers at several hundred meter depth.

Acknowledgements

The authors acknowledge VEOLIA Propreté for their contribution to the realization of this monitoring program and their technical support. The authors thank Veolia Environnement Recherche & Innovation SNC for permission to present this work.

References

[1] F. Hanot , N. Quisel, S. Thomas , N. Rampnoux. Pertinence of the seismic Claye Souilly siterocessing using existing seismic profiles in the Paris Basin; GHGT-10, 19-23 Septembre 2010, Amsterdam

[2] Y. Le Gallo, S. Fillacier, A. Lecomte, G. Munier, F. Hanot , N. Quisel, N. Rampnoux, S. Thomas. 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; GHGT-10, 19-23 Septembre 2010, Amsterdam

[3] Ph. de Donato , J. Pironon, J. Sterpenich, A. Laurent, M. Piedevache, Z. Pokryszka, N. Quisel, O. Barrès, S. Thomas, N. Rampnoux GHGT-10 CO_2 flow baseline: key factors of the geochemical monitoring program of future CO_2 storage at Claye-Souilly(Paris basin). ;GHGT-10, 19-23 Septembre 2010, Amsterdam

[4] H. Fabriol and al (2008), Géocarbone-Monitoring, Rapport final, BRGM/RP-56640-FR, Nov. 2008.

[5] H. Fabriol, M. Becquey, F. Huguet, M. Lescanne, G. Mouronval, J. Pironon, Z. Pokryszka, D. Vu-Hoang (2010) The Géocarbone-Monitoring Project: main results and recommendations for monitoring depth geological CO_2 storage in the paris basin. Oil & Gas Science And Technology, 2010, vol. 65, n° 4, 581-587

[6] F. Gal, K. Le Pierres, M. Brach, G. Braibant, C. Beny, A. Battani, E. Tocque, Y. Benoit, E. Jeandel, Z. Pokryszka, A. Charmoille, G. Bentivegna, J. Pironon, P. de Donato, C. Garnier, C. Cailteau, O. Barres, G. Radilla, A. Bauer (2010) Surface Gas Geochemistry Above The Natural CO_2 Reservoir Of Montmiral (Drôme-France), Source Tracking And Gas Exchange Between Soil, Biosphere And Atmosphere. Oil & Gas Science And Technology, 2010, vol. 65, n° 4, 635-652

[7] A. Battani, E. Deville, J.L. Faure, E. Jeandel, S. Noirez, E. Tocque, Y. Benoit, J. Schmitz, D. Parlouar, P. Sarda, F. Gal, K. Le Pierres, M. Brach, G. Braibant, C. Beny, Z. Pokryszka, A. Charmoille, G. Bentivegna, J. Pironon, P. de Donato, C. Garnier, C. Cailteau, O. Barres, G. Radilla And A. Bauer (2010) Geochemical study of natural CO_2 emissions in the french massif central: how to predict origin, processes and evolution of CO_2 leakage. Oil & Gas Science And Technology, 2010, vol. 65, n° 4, 615-633

[8] Ph. de Donato , J. Pironon , G. Mouronval , B. Garcia , H. Lucas , Z. Pokryszka ,P.H. Flamant, P. Cellier, K. Le Pierres. (2010) SENTINELLE : Development of combined geochemical monitoring from geosphere to atmosphere.10th International Conference on Greenhouse Gas Control Technologies, 19-23 September 2010, Amsterdam, The Netherlands.

[9] Z. Pokryszka., A. Charmoille,. G. Bentivegna , (2007) Développement des méthodes de suivi géochimique en phase gazeuse à la surface et dans la couverture intermédiaire des sites de stockage géologique du CO_2. Séminaire ANR Captage et stockage du CO_2 Pau,12-13 décembre 2007.

[10] Z. Pokryszka, A. Charmoille and G. Bentivegna (2010) Development of Methods For Gaseous Phase Geochemical Monitoring on the surface and in the intermediate overburden strata of geological CO_2 storage sites. Oil & Gas Science And Technology, 2010, vol. 65, n° 4, 653-666, on-line http://ogst.ifp.fr

[11] J. Raich, , W.H. W Schlesinger, (1992) The global carbon dioxide flux in soil respiration and its relationship with vegetation and climate. Tellus, 44B, 81-99.

[12] Ph. de Donato, J. Pironon, J. Sterpenich , L. Alain, M. Piedevache, Z. Pokryszka Zbignie, N. Quisel, O. Barrès, S. Thomas, N. Rampnoux(2011) - CO_2 flow baseline: key factors of the geochemical monitoring program of future CO_2 storage at Claye-Souilly (Paris basin)., Energy Procedia, 4 , 5438–5446

[13] Laj, P., J. Klausen, M. Bilde, C. Plass-Duelmer, G. Pappalardo, C. Clerbaux, U. Baltensperger, J. Hjorth, D. Simpson, S. Reimann, PF. Coheur, A. Richter, M. De Maziere, Y. Rudich, G. Mc Figgans, K. Torseth, A. Wiedensohler, S. Morin, M. Schulz, JD. Allan, JL. Attie, I. Barnes, W. Birmili, JP. Cammas, J. Dommen, HP. Dorn, D. Fowler, S. Fuzzi, M. Glasius, C. Granier, M. Hermann, ISA. Isaksen, S. Kinne, I. Koren, F. Madonna, M. Maione, A. Massling, O. Moehler, L. Mona, P. Monks, D. Muller, T. Muller, J. Orphal, VH. Peuch, F. Stratmann, D. Tanre, G. Tyndall, AA. Riziq, M. Van Roozendael, P. Villani, B. Wehner, H. Wex and AA. Zardini (2009). Measuring atmospheric composition change. Atmos. Environ., 10.1016/j.atmosenv.2009.08.020, 10.1016/j.atmosenv.2009.08.020, (33).

[14] C. Cailteau, Ph. de Donato, J; Pironon, A Vinsot, T. Fierz, C. Garnier and O. Barrès (2011) - In situ gas monitoring in clay rocks: mathematical developments for CO_2 and CH_4 partial pressure determination under non-controlled pressure conditions using FT-IR spectrometry, Analytical Methods, 3, 888-895

[15] C. Cailteau, J. Pironon , Ph. de Donato, A Vinsot, T. Fierz, C. Garnier and O. Barrès (2011) - FT-IR metrology aspects for on-line monitoring of CO_2 and CH_4 in underground laboratory conditions, Analytical Methods, 3, 877-887