On-site assessment of methods to measure gaseous emissions from biological treatment of waste

Isabelle Zdanevitch, N. Auvinet, Pascal Mallard, Olivier Bour

ON-SITE ASSESSMENT OF METHODS TO MEASURE GASEOUS EMISSIONS FROM BIOLOGICAL TREATMENT OF WASTE

I. Zdanevitch[a], N. Auvinet[b], P. Mallard[b], O. Bour[a] ([a]: INERIS, [b]: IRSTEA Rennes)

Contact: Dr Isabelle Zdanevitch, INERIS, Parc technologique ALATA, BP2, 60550 Verneuil-en-Halatte, France, 33-3 44 55 63 90, isabelle.zdanevitch@ineris.fr

EXECUTIVE SUMMARY

Landfilling of biodegradable waste must decrease to fulfil the Council Directive 99/31/EC on landfills, in order to reduce the emission of gaseous and liquid pollutants during the landfill lifetime. Therefore, pre-treatment of the organic fraction of municipal waste prior to landfilling is being developed in several countries. In France, the organic fraction is either separated and treated through selective collection of biowaste, or through mechanical sorting in the plant followed by biological treatments (anaerobic or aerobic), the refuses only being landfilled. Or the mixed waste is stabilized by an aerobic process before landfilling. These different processes emit gases which may be harmful for health or the environment (toxic, explosive, odorants, greenhouse gases...). Some of the emissions can be collected and treated through biofilters, while other gases are emitted by surfaces (typically, compost windrows) and cannot be collected unless they are enclosed. Also, the efficiency of the biofilters must be assessed. IRSTEA and INERIS have been working together for several years on the use, comparison and improvement of surface emission measurement methods, applied to biological treatment plants of solid waste.

Gaseous emissions were studied on: composting process of pre-sorted organic matter from mixed waste, with a small or larger mesh and porosity, in either turned or aerated windrows, on biofilters, and on landfills which are located beside the composting plants. Depending on the ventilation air flux, different measurement methods were used: static (accumulation), dynamic or chimney type chambers, and a total cover of a biofilter with a plastic tarb. Several of these measurements were undertaken in order to evaluate the global gaseous emissions from those sites, to provide data to an environmental technology validation exercise (ETV).

Measurement campaigns presented here comprise: comparison of fluxes measurement techniques, calculation of gas fluxes (CO_2, CH_4, NH_3 and N_2O) emitted from composting windrows and biofilters, calculation of biogas emission (methane + CO2) before and after a final cover was set on a landfill.

Comparisons of the two first chambers have been made since 2007 on several sites (composting of the organic fraction of municipal solid waste or stabilization prior to landfilling). On the first site (non aerated windrows and small mesh) the difference between the measured fluxes was a factor of 2. This factor is rather small: differences between flux measurements using different devices can lead to differences as large as a factor of 100. More recent tests, presented here, show a better agreement: the difference between the two techniques lies within the measurement uncertainty.

Comparison of surface air speed measured by two different chimney chambers lead to comparable results. During one experiment, the global air flow interpolated from chamber data was underestimated compared to input flow measurement, because of preferred pathways of the air flow along the wall of the biofilter. When the border effect is correctly taken into account, the total gas flow measured with the chimney chamber and the one measured by a total cover of the biofilter show a good agreement.

Biogas surface emissions were measured with the static chamber, on a landfill which receives biologically stabilized waste. This landfill was partly uncovered, so only a part of the biogas was collected and flared. After the final cover was installed, the total biogas flow which was collected and flared was comparable to the sum of (the surface emissions + the collected biogas) without the total cover.

The results presented here show that on different sites, different emission measurement methods were used, and that generally there is a good agreement between the methods, providing the care of use are respected.

Advantages and care of use for the different methods, depending on the aeration conditions, have been established and some recommendations are given.

1 INTRODUCTION

Landfilling of biodegradable waste must decrease to fulfil the Council Directive 99/31/EC on landfills, in order to reduce the emission of gaseous and liquid pollutants during the landfill lifetime. Therefore, pre-treatment (sorting or stabilization) of the organic fraction of municipal solid waste prior to landfilling is being developed in several countries, named mechanical-biological treatment (MBT). In several locations in France, the organic fraction is separated and treated either through selective collection of biowaste, or through mechanical sorting in the plant followed by biological treatments (anaerobic or aerobic), in order to produce compost. In the latter case only the sorting refuses are landfilled. In some plants, mixed waste containing organic matter is stabilized by an aerobic process before landfilling. These different processes emit gases which may be harmful for health or the environment (toxic, explosive, odorants, greenhouse gases...). Some of the emissions may be collected and treated through biofilters, while other gases are emitted by surfaces (typically, compost windrows) and cannot be collected unless they are enclosed. Also, the efficiency of the biofilters must be assessed.

1.1 Background

The environmental assessment of the biological treatment of biodegradable waste takes into account all the emissions of the treatment plants and the outputs when they are valorised or landfilled. Among them, surface gaseous emissions may be important and need to be evaluated. Standard methods exist for the precise determination of exhaust or flare emissions, but surface emissions are more difficult to measure quantitatively. IRSTEA and INERIS have been working together for several years on the use, comparison and improvement of surface emission measurement methods, applied to biological treatment plants of solid waste

1.2 Research objectives

The research project, conducted in the partnership aimed to compare different surface emission measurement chambers that were available, and, depending on the process or area to be monitored, to give recommendation for the selection and use of the appropriated chamber(s). Gaseous emissions were established on different MBT plants and associated landfills in order to provide data for an environmental technology validation exercise.

2 METHODOLOGY

Gaseous emissions were studied on different plants, comprising: composting of pre-sorted organic matter from mixed waste, with a small or larger mesh and porosity, in either turned or aerated windrows, on biofilters, and on emissions from the treatment buildings or devices such as rotating drum bioreactors. Surface emissions of landfills which receive either stabilised waste or sorting refuses, associated to the biological treatment plants, were also investigated.

2.1 Measurement of surface flux gases

Depending on the ventilation air flow, different measurement methods were used:

1) a static flux chamber developed by INERIS allows short time measurements on rather small or medium fluxes (typically less than 5 L/m^2/min). In this chamber, gas emitted by the soil or compost surface accumulates This method, applied to a great number of measurement points, gives a set of local fluxes which can be interpolated by kriging, in order to cartography a zone and calculate the total flux over the area. It has been used for the emission measurement on landfills surface, and on non-aerated or aerated windrows with low aeration speeds. 2 analyzers measure methane and CO_2 simultaneously;
2) a dynamic flux chamber developed by IRSTEA takes longer time for one measurement, but allows measurements on higher fluxes and can be used for monitoring the fluxes variations over a period of time. In this chamber, there is an admission and an extraction of the outside air, with a control of the pressure equilibrium between the inlet, outlet and outside of the chamber. The measurement can be done without effect of overpressure (under-estimation of gases emissions) or depression (over-estimation of gases emissions) in the chamber. It was designed to capture convective emissions and has been also used on non-aerated and aerated windrows. Gaseous concentrations are measured by an INNOVA analyzer, measuring on the same time CO_2, CH_4, NH_3, and N_2O (possibly SF_6) in the ppm range;
3) for larger emitted air flows (typically, on biofilters) a chimney chamber is more adapted. The chamber outlet is constituted of a reduced tubing, increasing the gas speed, which is measured more accurately. Both INERIS and

IRSTEA have such a chamber, designed in different geometries and materials. Different types of analyzers can be connected to these devices (the first measurement is the air speed).

2.2 Measurement campaigns

Measurement campaigns were undertaken on several waste treatment plants. They are shortly described thereafter.

2.2.1 Site A

This site is a composting plant which processes municipal solid waste. Raw waste is pre-treated in a rotating bioreactor (drum) for 4 days. During this time, waste bags are opened, and paper and cardboards are somewhat decomposed in small pieces. After this pre-treatment, waste is carefully sorted through different devices in order to obtain a clean and fine organic fraction. Before 2010, this fraction was mixed with a bulking agent (shredded green waste) and disposed in windrows which were turned twice a week with an automatic windrow turner (A1). Since 2010, the mixture is disposed in successively 2 aerated cells, with a discontinuous aeration, for 3-4 weeks each. After that, the compost is stored outside without any turning until it is taken by local farmers to be used on fields (A2). Polluted air from the composting boxes and the rotating drum is treated by biofilters (A3 and A4 respectively). The refuses of sorting are stored in a landfill which sits on the same site (A5).

2.2.2 Site B

Site B is an anaerobic digestion (AD) plant which also processes raw MSW. The pre-treatment and sorting of the organic matter is quite similar to the one of site A, but after the sorting the organic matter is hydrolyzed (dry conditions, around 30 % dry matter) and sent to large digesters (volume approximately 1500 m^3) for 1 month. Feeding of the reactor is semi –continuous and temperature is kept at 37 °C (mesophilic conditions). The digestate is then dried by pressing, mixed with crushed green waste, and composted in aerated boxes for 14 days: air from this process is treated through an acid washing tower followed by a biofilter (B1). The compost is then stored for maturation without turning (B2, before 2012), until it is used by local farmers, between 1 and 3 months after. Since our measurements, the site manager has decided to turn the maturating compost every week or so, in order to limit the methane emissions to the atmosphere. Efficiency of this new procedure will be evaluated. Refuses of sorting are sent to an outside landfill or incinerated: no emission measurement was possible on this fraction.

2.2.3 Site C

Site C processes MSW, but do not prepare a compost for agricultural purpose. The waste is biologically stabilized before landfilling. The larger fraction of waste (> 50 and 70 mm typically) is not stabilized. A part of the plastics (fraction between 70 and 450 mm) is sorted and recycled. The larger fraction, and the refuses of the intermediary fraction, are landfilled without treatment. The smaller fraction, which is rich in organic matter, is treated in aerated boxes for 2.5 months (C1). Aeration is discontinuous, with a 3 minutes-3 minutes cycle. Treated matter is moved from one box to another one, every 2 weeks. Stabilized matter is used as a temporary cover, every week or so, on the landfill cells (open cell: C2, closed cells: C3)

3 SURFACE EMISSION MEASUREMENT ON NON AERATED WINDROWS

3.1 Emissions from composting and maturation windrows, composting site

The first measurements were performed in 2007 on site A. Methane and carbon dioxide were measured with both a static chamber and a dynamic chamber on several windrows of different ages (A1, A2) and on the landfill cells (A5): “EMISITE”, 2007, and Zdanevitch *et al*, 2009) Individual measurements taken with the static chamber were used for emission cartography by kriging, using Surfer 8. Figures 4 and 5 show methane and CO_2 emissions on the same windrow. Table 1 reports the total methane and CO_2 fluxes for windrows of different ages.

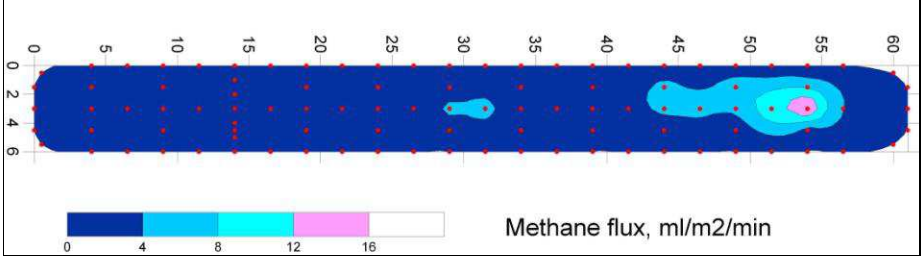

FIGURE 1 **Methane flux determined with a static chamber, non aerated windrow (windrow size in meters)**

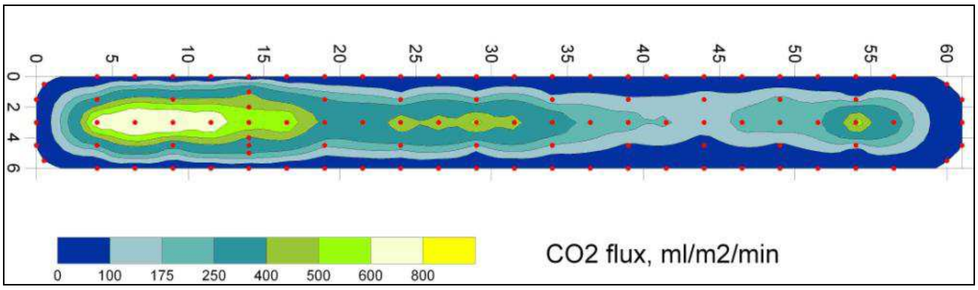

FIGURE 2 **CO_2 flux determined with a static chamber, non aerated windrow (windrow size in meters)**

TABLE 1 **Methane and CO2 emissions from non aerated windrows, depending on the age of the compost**

Windrow	Age	Surface, m^2	CH_4 flux, m^3/h	CO_2 flux, m^3/h
7	15 days	366	0.04	4.5
6	1 month	294	0.34	4.6
Mat	3 months	432	0.82	4.3

Discussion: CO_2 emissions from composting at different ages were quite similar. The maturation windrow was larger but also higher than the composting one (6 and 7), so CO_2 emission, related to the quantity of matter, is a little lower, but in the same order of magnitude. This suggests that the first stage of composting is not sufficiently efficient. Methane emissions are more scattered: they are very low on young compost (less than 2 weeks). They increase with the age of the compost, and also on the maturation windrow, which is not turned.
Comparison of results between fluxes measured by the static chamber and the dynamic chamber led to differences between 1 and 5 (mean value around 2: "Emisite", 2007). These differences could not be completely understood, so comparison was repeated during other campaigns (see chapter 4).

3.2 Emissions from maturation windrows

As we noticed in 2007, methane emissions can be large on undisturbed windrows. Site A, after a modification of the composting conditions, and site B, store compost in large windrows, without turning, for 1 to 3 months before its use on agriculture soils. We measured methane and CO_2 emissions on maturation windrows on these two sites (A2, B2) with the same method, the static flux chamber. Results are presented in table 2.

TABLE 2 **Methane and CO_2 emissions measured on maturation windrows**

		Surface, m^2	CH_4 flux, m^3/h	CO_2 flux, m^3/h	Relative CH_4, $m^3/h/m^2$	Relative CO_2, $m^3/h/m^2$
Site A (MBT, composting alone)	**Windrow 1**	272	7.2	26	0.03	0.10
	Windrow 2	380	9.4	40.2	0.02	0.11
Site B (MBT, AD and composting	**2 windrows (Oct. 2010)**	500	13.7	22.4	0.03	0.04
	1 windrow (May 2011)	300	6.1	11.5	0.02	0.04

Discussion: methane emissions are rather important, showing that anaerobic conditions prevail inside the composting windrows, and that the compost is not stabilized despite its age. Emissions are very similar between the two sites, e.g. there is no influence of the anaerobic digestion prior to composting on the methane emission potential of the compost. Nevertheless, CO_2 emissions are similar between windrows of the same site, but 2 to 3 times lower on site B (with AD) than on site A (composting alone). This shows that 1 month of AD followed by two weeks of aerated composting probably biodegrades more the organic matter than the 2 months of aerated composting. In order to compare the results, emissions have been reported to the surface. They should be reported to the mass of compost, but this information is not yet available.

4 SURFACE EMISSION MEASUREMENT ON AERATED WINDROWS

Parallel measurements using static and the dynamic chambers, were undertaken on the composting boxes of site C (C1). The measures where done on three boxes, which contained the fine waste fraction of different ages. The aeration cycle has been lengthened from the standard one: 3/3 minutes with/without aeration, to 15/15 minutes, to allow the measurement with the dynamic chamber and INNOVA analyzer. Measurements with the static chamber being faster, several measurements can be made successively during the aeration or non-aeration stage. Figures 6 and 7 report measurements made with the 2 chambers on the same windrow, the same day, during non aerated and aerated cycles.

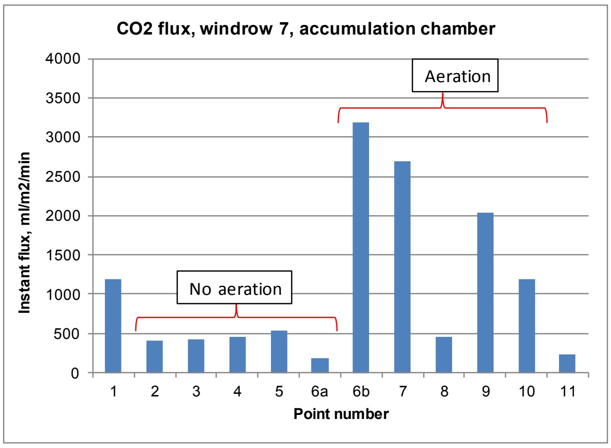

FIGURE 3 **CO_2 flux measured with the static chamber**

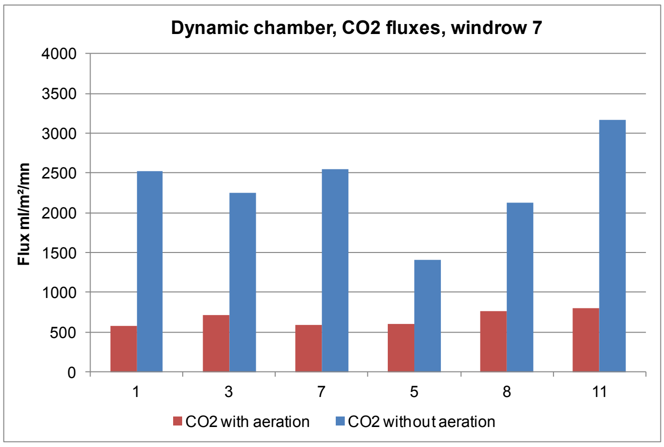

FIGURE 4 **CO_2 flux measured with the dynamic chamber**

TABLE 3 **Comparison of CO_2 surface flux on windrow 7, established with the static and the dynamic flux chambers**

Mean CO_2 flux, $m^3/m^2/day$		
Static chamber	Dynamic chamber	Difference, %
1.97	2.26	13

Despite different measuring times (2 minutes for the static chamber, 10-20 minutes for the dynamic chamber), it is interesting to notice that the results of the two chambers are similar. The static flux chamber is able to differentiate emissions with and without aeration, although this chamber was not initially designed for aerated surface sources The difference between the mean flux (sum of the aerated and non-aerated periods) is as low as 13 %. It should be noticed that the overall uncertainty of the static flux chamber measurement technique (assuming that measurements are made over several days periods) has been evaluated around 20 %. Knowing the total surface of the windrows (corresponding to a given mass of compost) allowed us to calculate the total CO_2 emissions for the whole composting plant, and to compare it with the emissions from the landfilled stabilized waste. These results will be used for an environmental technology validation exercise (ETV) and will be published shortly.

5 SURFACE EMISSION MEASUREMENTS ON BIOFILTERS

5.1 Biofilter treating the air from the composting boxes on site A (A3)

Gaseous fluxes cartographies (kriging interpolations) were established on this biofilter using a chimney chamber. During a previous experiment, the global air flow interpolated from chamber data was underestimated comparing to input flow measurement, because of preferred pathways of the air flow along the wall of the biofilter. On this site, care has been taken on this point. Two different analysers were connected to the chamber: an ECOPROBE 5 (infrared), measuring CO_2 (and hydrocarbons but at rather high concentrations, useless here), and an INNOVA (photacoustic) which measures simultaneously 4 gases (CO_2, CH_4, NH_3, N_2O) in the ppm range. Along with the cartography of the biofilter, the results gave a comparison of CO_2 fluxes measured on the same device with the two analyzers: see table 4.

TABLE 4 **Emission measurements (CO_2, methane, NH_3, N_2O) on the composting boxes biofilter on site A**

Biofilter (Air from compost. boxes, S = 216 m^2)	CO_2 (ECOPROBE)	CO_2 (INNOVA)	CH_4 (INNOVA)	NH_3 (INNOVA)	N_2O (INNOVA)
Flux, m^3/h	9,1	10,6	0,59	0,009	0,003

The difference between CO_2 fluxes measured by the two analyzers is 16 %. It is similar to the difference that was measured on the aerated windrows with two types of chambers. It means that the difference between flux measurements is probably due to analyzers uncertainties, as well as the difference between techniques. CO_2 flux is 16 times larger than CH_4 flux, a thousand times larger than NH_3 flux, and 3 thousand times larger than N_2O flux. This allows the calculation of warming effect due to greenhouses gases emissions from this biofilter (NH_3 is not a GHG but has also environmental impacts). Once again, these results will soon be used in an ETV exercise.

5.2 Biofilter treating the air from the rotating drum on site A (A4)

On the same site, surface CO_2 emissions were measured on a biofilter treating the air from a rotating drum. Different methods were tested to follow the gas emission evolution. First, a cartography of the biofilter CO_2 emissions was established using the chimney chamber (see figure 8). The other method consisted in covering the whole biofilter surface with a plastic tarp, in aim to measure all the gas emissions.
With these two methods, it was possible both to cartography the biofilter emissions, and to follow the total emissions during time and characterize the treatment efficiency of the biofilter.

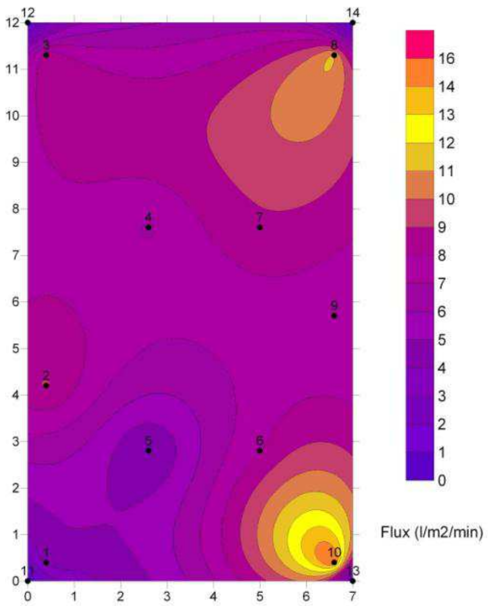

FIGURE 5 **CO_2 fluxes determined with a chimney chamber**

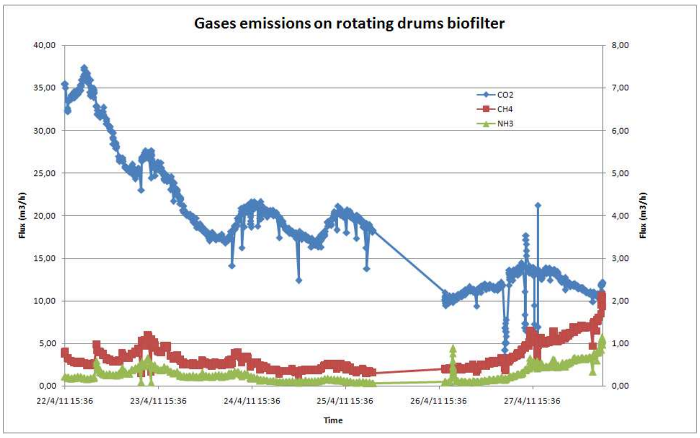

FIGURE 6 **Gases emissions monitoring on the rotating drums biofilter**

Results on figure 6 show that we obtain similar values for the first 2 two days (April 21-22) but the following days, the plastic sheeting method shows a trend of decrease. The decrease can be explained for the three following days by the week-end (from the 23 to 26th of April), and the fact that there is no new matter entering in the rotating drum. It is more complicated to explain why this decrease continued on the following days, when the site activities came back.

TABLE 5 **Emissions measurements (CO_2, CH_4, NH_3, N_2O) on the rotating drums biofilter on site A**

Biofilter (Air rotating drums, S = 84 m^2)	CO_2 (SURFER) 2011/04/21	CO_2 (INNOVA) 2011/04/22	CH_4 (INNOVA) 2011/04/22	NH_3 (INNOVA) 2011/04/22	N_2O (INNOVA) 2011/04/22
Flux, m^3/h	39	34,82	0,58	0,19	0,01

Comparing to the gaseous emissions of the two biofilters of site A shows that the rotating drum's biofilter presents higher gases emissions. It can be explained for a part by the fact that, at this time, the composting boxes where open, due to a functioning problem. So, the composting biofilter treated only a part of the gaseous emissions. New measurement should be done on composting biofilter with closed boxes.

6 SURFACE EMISSION MEASUREMENT ON LANDFILL CELLS VS FLARED BIOGAS

On site C, "stabilized" waste is landfilled. In fact, even after 2.5 months of active composting, the organic fraction of MSW is not completely stabilized, and when it is landfilled under anaerobic conditions, biogas builts up. This biogas contains approximately 55-60 % v/v methane, 35-40 % v/v CO_2, and trace gases like H_2S up to 800 ppm. Initially on this site, biogas was not burned as the total flux was supposed to be low. But neighbours reported odour problems due to H_2S, therefore a flare has been installed. When we measured the surface gaseous emissions of the landfill (July 2011), the flare had been used for 4 months and biogas was pumped only on closed cells (C3). The static chamber was used to measure biogas (methane + CO_2) emissions on the surface of the landfill (C2 and C3). Figure 8 represents the methane emissions. Different areas of the landfill have been identified:

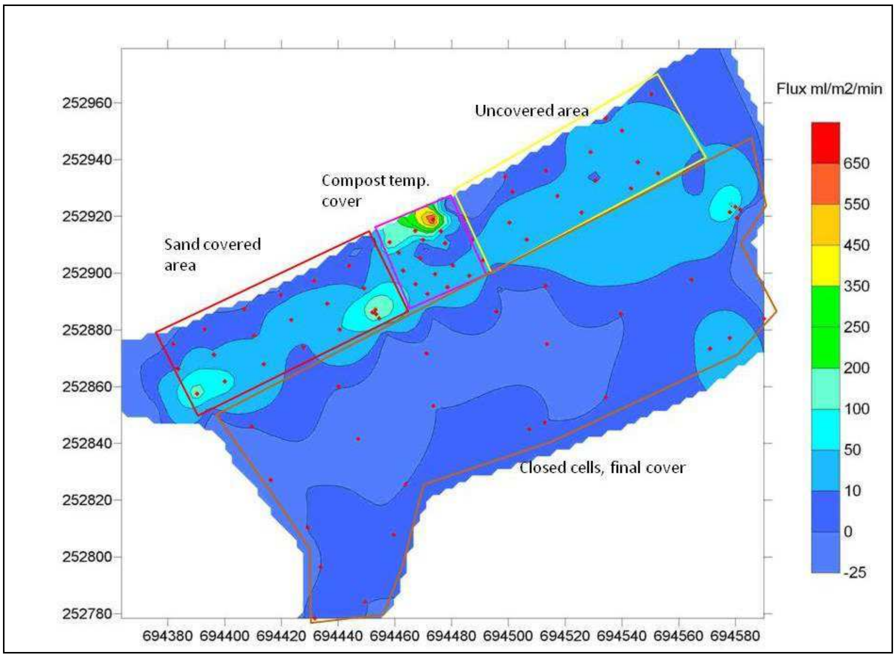

FIGURE 7 **Methane surface emissions on site C (landfill cells)**

TABLE 5 **Calculation of total biogas flux from the whole landfill, site C (July 2011)**

	Mean flux, m^3/h	
Methane, surface, static ch.	17 (a)	Total biogas flux (surface + flared) : **85**
CO_2, surface, static ch.	43 (a)	
Flare, biogas from 6 wells (data from the plant manager)	25	

(a) Though biogas is richer in methane than in CO_2, CO_2 surface fluxes are higher than methane ones. It implies that a fraction of methane is oxidised within the surface layers (constituted of mixed sorting refuses and compost) before it is emitted to the atmosphere.

4 months after our measurement campaign, the exploited zone of July had its final cover and biogas was pumped through 14 biogas wells distributed all over the landfill area. The mean biogas flux burned by the flare was then 70-80 m^3/h. This represents a difference with the estimated total flux of July, of about 6 to 17 %. Once again, this difference lies within the normal uncertainty of the static chamber measurements.

7 RECOMMANDATIONS

The choice of the measurement technique (type of chamber, gas analyzer) depends on the application. First of all, it is important to know what are the aim and the uses of the measures.

If the aim is to cartography an area, choices are static chamber for a compost windrow or chimney chamber for a biofilter. There must be a careful consideration on the measurement strategy to place the points of measurements (on a windrow, at least one row on the top and one, or better, two rows on the edges). The number of points depends on the dimensions of the area and on the variation of the fluxes between points. Even if the area is small, a minimum of points is needed in order to get a good kriging. Typically, a minimum of 20 to 30 points give good results when fluxes are rather stable over the area. Border effects must also be taken into account, especially on biofilters, depending on the type of filtering material. If it is rather coarse, preferred pathways can exist along the wall of the filter. The chamber must be placed in contact to the wall in order to take this phenomenon into account.

Measurements with a static chamber are fast and allow a large number of measures in a short time; but if there are quick changes in the flux, this technique can lead to wrong results. On the other hand, it is possible to repeat measurements and to calculate the mean value.

Measurements with a chimney type chambers take longer. These chambers are very useful for flux measurements on biofilters, but there is little information on this technique in the literature. The following points are important: first, to measure the gas concentration correctly, the volume of the chamber must have been replaced at least 6 times; this depends on the volume of the chamber and on the gas flux. The air speed may have changed between the start and the end of the measurement: it must be controlled, and if the difference is too high, the measurement should not be kept.

To measure fluxes along time, the dynamic chamber is well suited. It allows long time measurements, which is useful to integrate changes in emissions along the changes in process (as example aerated windrow). The measure depends on the pressure inside the chamber which must be controlled and measured.

On a biofilter, covering the whole surface with a plastic tarb is a good alternative to follow emissions of a process along time, but the installation is tricky and takes a long time.

8 CONCLUSIONS

They are several available techniques for gas fluxes measurements and the choice will depend on the application. The strategy of measurement is important and must be thought before the on-site campaign. All the campaigns run together by INERIS and IRSTEA allowed us to raise some recommendation about gas measurements.

When there is high variability in the gaseous emissions in a process, measures will be more representative if the emissions can be followed along time. Depending on the process, short measurement times can give random results which can introduce a misunderstanding of the process gases emissions, or mistakes in the calculation of gaseous emissions.

The static chamber is a good method to cartography large surfaces (like landfills) because of its quickness. It can also be used on compost windrows. It allows the measurement on a large number of points over a short period of time, which allows precise determination of highly emissive points (“hot spots”).

The dynamic chamber is better used for a continuous monitoring over a long period of time. Chimney chamber is useful on processes with high aeration speeds as biofilters.

Comparison of methods, between static chamber and dynamic chamber, gave recently good results on some sites, but more tests should be necessary to get a better comprehension of the differences observed in the past.

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