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PASSIVE BIOMITIGATION OF DIFFUSE LANDFILL GAS EMISSIONS ON 12 FRENCH LANDFILLS: RETURN OF EXPERIENCE ON DESIGN CRITERIA USED

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SUMMARY: More than 12 french landfill sites were equipped with a biomitigation system for the treatment of Landfill Gas (LFG) emission. This treatment was used primarily for remediation at old landfills. The use of biowindows or passive biofilters in the specific case of passive LFG emission treatment needs to take into account specific parameters. These parameters are linked to the LFG production, the location, the geometry of the LFG drainage and the quality of the final cover on the landfill. Return of experience on 12 french landfills let us to differentiate between two major approaches used for the selection of methane emissions passive biomitigation equipment. In the first approach we use a design parameter that comes from LFG production modeling completed by parameters taking into account the water balance and the ratio of the landfill surface to biowindows/biofilters area. The second approach concerns the use of concentrations and fluxes measured on the surface and from the LFG drainage wells. Description of the criteria used for the choice of biomitigation treated LFG is given for 4 french landfills, including detailed information about the biomitigation system used for 12 french landfills.

1. INTRODUCTION

Numerous studies concerning passive and active methane oxidation on pilot and full scale have initiated the use of biomitigation processes for the treatment of the LFG emissions, especially on old landfills.

Concerning the biomitigation design, the use of a compost medium for the methane oxidation medium within a scheme of two layers (0.15-0.5 m coarse gravel and 1-1.2 m mature compost) was presented (Huber-Humer and al, 2008; Kjeldsen and al, 2009). An assesment of the methane oxidation efficiency (41%- 99.7%) of large scale biomitigation system (Scheutz an al, 2011) was also produced. The advantages and drawbacks of the two majors passive biosystems used (biowindow and biocover) were discussed (Huber-Humer and al, 2008) and guidance documents are available (Huber-Humer and al, 2008, 2009; DECCW, 2010). The lower gas permeability of the cover, the absence of an active collection system and the location of the methane load are the principal parameters for the use of biowindows and passive biofilters.

For the biowindows and passive biofilters, the efficiency of the drainage system is one of the major parameters of the efficiency of a biomitigation system (Chassagnac and al., 2007; Kjeldsen and al., 2009; Dever and al., 2010). This parameter contributes in a large part to the distribution of the methane load in the biotic system, and to the solution for large biotic systems (Scheutz and al., 2011). One of the goal of the biotic system is to treat the area of large methane emission, coming from heterogeneity of the cover or from the problem of cracks near the wells in the aftercare period (Åkerman and al., 2007, 2011). Another parameter is the contribution of the vegetation to a better supply of oxygen, especially to the fined grained soils (Bohn and al., 2011). The root systems could improve the methane oxidation but also could create preferential flows (Scheutz and al., 2009).

A methane load around 125 L $CH_4/m^2/d$ (or 80 g $CH_4/m^2/d$) was accepted as a base for the treatment sizing. A porosity rising 25 % (v/v) and if possible more than 30% (v/v) in the methane oxidation medium (MOM) was also recommended (Huber-Humer and al., 2009).

The design and the location of the biowindows or passive biofilters in the specific case of passive LFG emission biomitigation needs primarily to consider the distribution of the residual methane load on the landfill surface.

These two parameters are linked with the residual LFG production assesment, the location and the geometry of the projected LFG drainage, and the quality of the final cover (gas permeability). For 12 landfills equipeed with passive biomitigation system, we have differentiated two major approaches for the selection of passive biomitigation for the reduction of methane emissions.

In the first approach we use primarily a design parameter coming from the LFG production modelling. When data on the waste stock are not available for an old landfill, assumptions need to be done to evaluate a global production of the LFG and the emission of methane. The location and the open area of a biofilter/biowindow are also determined with parameters of the water balance and the ratio concerning the landfill surface and the biowindows/biofilters surface. In the case of landfill remediation, the LFG emission treatment is generally combined with the goal of a decreasing level of the rain infiltration. The location of the passive drainage and biomitigation of methane emission can be fixed with a tumulus relief and for the case of a whole landfill zone: the limits of the area of the passive LFG drainage could be limited during the remediation with trenches and use of high/low permeability materials.

The second approach concerns the use of concentrations and fluxes measurements on the surface and from the LFG drainage wells. The surveys done during the METHALIX research program ((Åkerman and al., 2011) have highlighted the importance of the location of the emissions, especially around the LFG drainage wells for the low permeability final covers which are generally used in France.

2. METHODOLOGY

2.1 Parameters of the two approaches

For the approach based on the LFG production modeling, the knownledge of the waste deposit and degradation kinetics for each of the waste fraction is needed. Some survey concerning the carbon content and the annual average moisture of the waste could also be used to estimate these parameters. The LFG production modeling gives the total amount of the LFG produced. The expertise of the LFG drainage possibilities is combined with the LFG production modeling to assess a methane load for the biomitigation processes.

For the LFG surface measurements approach, the first step is the identification of the emissions areas and the assessment of the methane emission distribution of the final cover, in order to compare the naturally occurring methane oxidation (with the hotspot locations of the methane emission). Favorable conditions of methane oxidation are expected for the cover with a sufficient fraction of organic matter and/or a coarse grain size (i.e. sandy to sandy loam layers, Gebert and al., 2009). In a second step, a local measurement method of the LFG flux combined with a sampling design could be used to asses the methane and CO_2 fluxes coming for the largest contribution area.

That two steps approach allows to observe the distribution of the methane load for a biowindow.

This survey phase also produces the methane emission assessment figures, which can be compared with the methane emissions thresholds proposed for the use of passive treatment (Bour and al, 2005).

2.2 Passive biomitigation parameters

Two different designs were used: biowindow and passive biofilter. The design parameters include:

- type of the MOM used,
- surface and thickness of the MOM,
- type and thickness of the gas distribution layer (GDL).

The load and the efficiency of the biomitigation system could also be assessed. The measurements methods was generally the flux chamber associated with pore gas profile and/or methane surface screen. These measurement associations allow to use the mass balance method. A mass balance could be evaluated on the methane or on the carbon, assuming a few assumptions.

The methane mass balance suppose to have a rather good estimate of the methane load before the treatment, also it was general only used for the system with a channeling of the load through a casing, for the passive biofilter. The use of the carbon mass balance needs some hypothesis (Christophersen and al., 2000) on methane oxidation and on the carbon dioxide production coming from the MOM.

3. CASE STUDY SITES

3.1 Case study sites with LFG modeling approach

3.1.1 case study : Maugio landfill

The Mauguio (34) landfill was operated between 1950 and late 1990. Located southeast of downtown, it fills a part of the Plagnol Marsh on 10 ha at an altitude of 0 m asl. The volume of waste stored with a high organic content is estimated at around 600 000 m^3.

The exploitation of this landfill has taken place under conditions which conduct to a phase of an aerobic degradation: large operating surfaces coupled with limited waste thickness (the highest point reachs 10 m asl), regular burning, low number of intermediate covers. During the preliminary diagnosis to rehabilitation, spot measurements of biogas emission showed average methane concentrations between 10 and 35%.

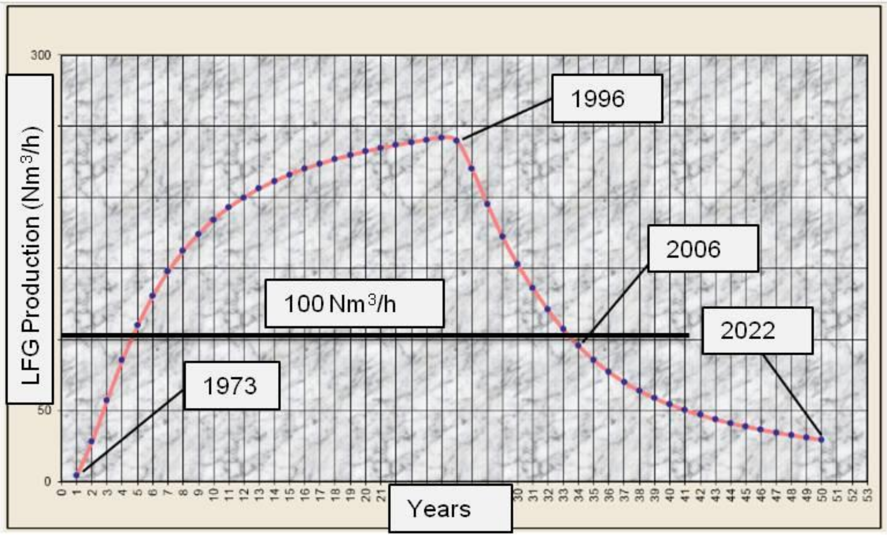

Figure 1. LFG production curve of the Mauguio landfill.

Modeling biogas production via the PRODGAZ software produce an hourly flow curve that does not allow the regular operation of a flare (cf. Figure 1). Indeed, in 2005-2006, years of remediation work, biogas production was estimated around 100 Nm^3/h, or less than 30 Nm^3/h of methane

The solution to treat the residual biogas emission by a biofilter was choiced. Located at the highest point of the redeveloped landfill (cf. Figure 2), it was sized to treat the entire biogas collected under the cover in a filter medium of approximately 400 m^3 (20m x 20m x 1m). The medium was a mix of pozzolan and coarse compost of green waste.

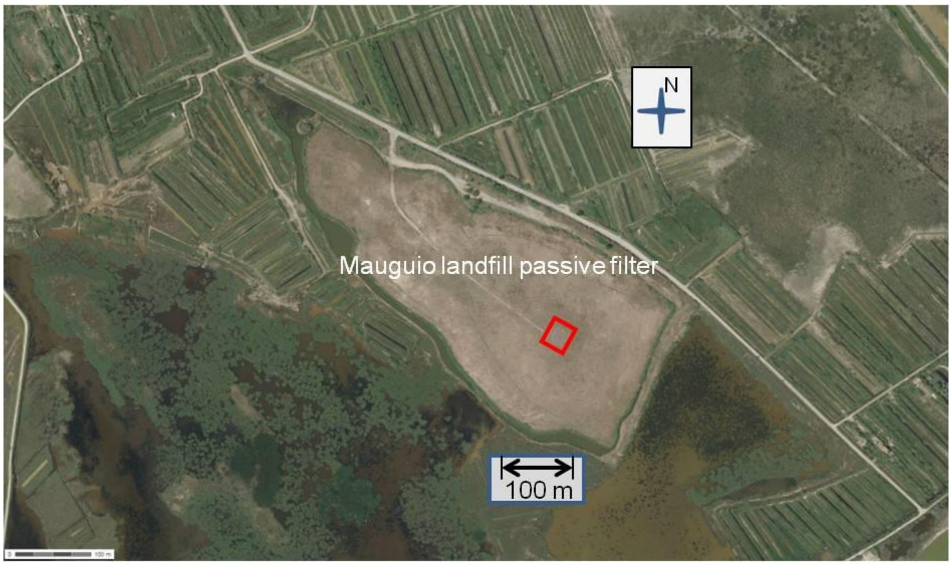

Figure 2. Location of the Mauguio passive biofilter (base map : IGN Geoportail ®)

3.1.2 case study : Rimeize Landfill

The landfill Rimeize (48) was operated between 1993 and 2003 at a rate of 10 000 tons / year.

Located in the center of a valley at an altitude 1000 m asl, it occupies an area just under 2 ha.

The mass of waste stored with a high organic content is estimated at around 100 000 tons. The exploitation of this landfill has taken place under conditions which favored a predominantly anaerobic degradation: small operating surfaces coupled with regular collections, significant waste thickness (40 m, at the highest point).

During the preliminary diagnosis for the remediation, spot measurements of biogas emission showed average methane concentrations between 20 and 50%. In parallel, LFG modeling production via the PRODGAZ software, led to an hourly flow which not allows the regular operation of a flare. Indeed, in 2003, the year of the end of operationnal phase, biogas production has been estimated at around 80 Nm^3/h, or less than 40 Nm^3 /h of methane.

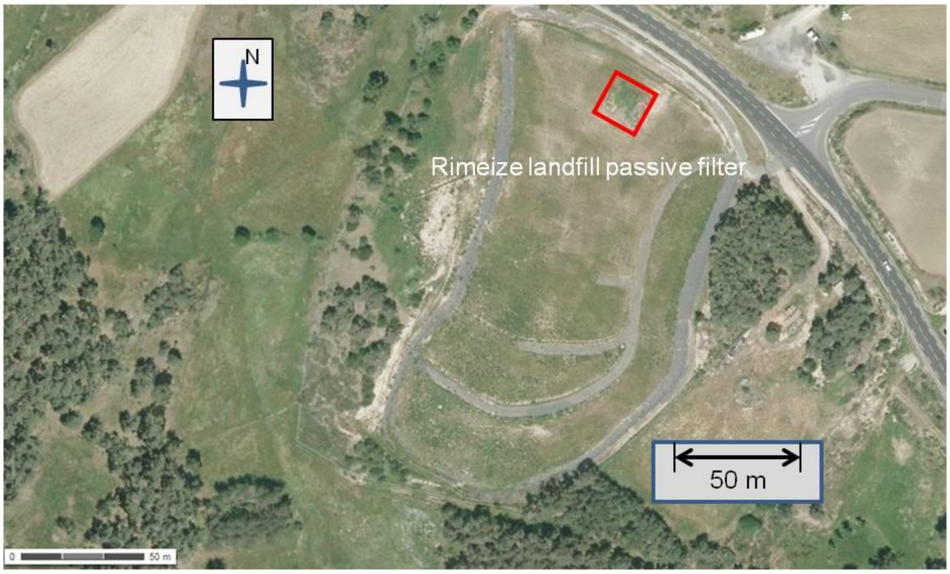

Figure 3. Location of the Rimeize passive biofilter (base map : IGN Geoportail ®)

A biofilter of 300 m^3 (16 m x 16 m x 1m) collecting all the biogas under the cover was implemented at the highest point of the redevelopped landfill (cf. Figure 3). The filter medium was pozzolan mixed with coarse compost of green waste.

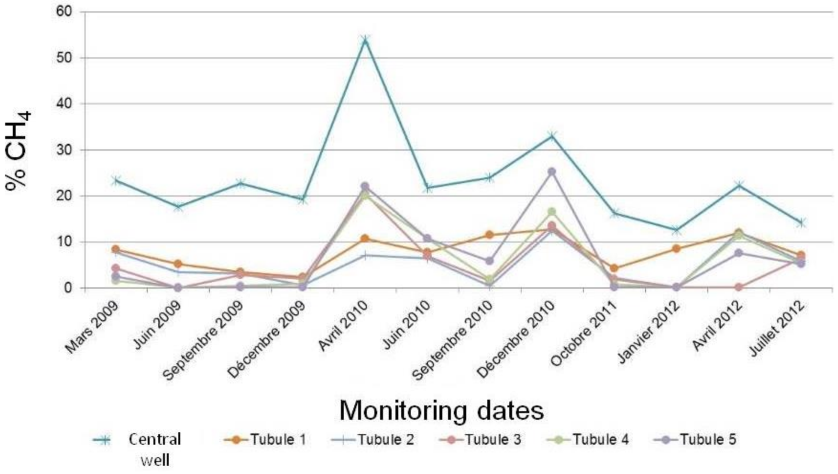

Figure 4. Monitoring of methane percentage in the air probe gas (biofilter on.Rimeize landfill).

The Monitoring of the efficiency of the biofilter was conducted over a period of 4 years. It indicates a reduction of 50 to 100% between the amount of methane collected in the central well (before treatment) and those measured after treatment. The monitoring was done with 5 air probes (named “tubule 1” to “tubule 5”) installed during the construction of the biofilter (cf. Figure 4).

3.1.3 case study : Le Moule Landfill

The landfill of Le Moule in Guadeloupe (971) was operated between 1982 and 2008. Located in the inland, it has been operated in the filling of a former quarry and reached twenty meters thick at the highest point with a surface just over 1 ha. Total tonnage stored is estimated at 160 000 tons, with a fraction of biodegradablewaste of around 60%. The operationof this landfill has taken place under conditions which contributed to a predominantly aerobic degradation (large operating surfaces).

The LFG production modelling does not allow to consider the regular operation of a flare. The peak production at the end of operations was calculated at 38 Nm^3 /h of methane. The office in charge of programming studies had then recommended to degassing the site through vents. As part of its project management mission of the landfill remediation rehabilitation, EODD, combined with local firm RHEA Environment Antilles, proposed replacing these passive vents by a biofilter.

Degassing to avoid LFG rising pressure under the GSB was required. The passive venting solution was abandonned, due to the potential source of additional risks and nuisances of this degassing without treatment. Positioned at the highest point of the remediated landfill, the biofilter has been sized to treat all of biogas collected under the cover in a filter medium of about 300 m^3 (16 m x 16 m x 1 m) consisting of pozzolan and coarse compost green waste.

3. 2. Case study site of LFG surface measurements

3.2.1 case study : site A

The site A is located in the north of France. The waste ages are in the range 12-30 years in this landfill area. The waste fractions are composed of non hazardeous municipal solid waste (MSW), with an inert and ash fraction. This landfill has a collection system in operation during the after care period. But due to the low production of LFG (< 100 m^3/h) from this zone, the operators are interested to test a new passive biosystem. The residual methane production were assessed by a two step surveys, combining methane surface screening and methane and carbon dioxide fluxes measurements. The final cover is composed of clayed materials with a géocomposite liner at the base of the cover. The methane surveys were done after shuting down the active collection during a period of 3 weeks. The results shows that the hot spots are located near the wells with almost no methane diffuse emissions on the other part of the cover. The quality of the LFG was relatively constant over the collection system of the tumulus with a methane fraction of 60% for the landfill gas during this survey phase. This result allows estimating a methane load and an efficiency of the initial cover with the carbon mass balance method (cf. Figure 6). The average methane oxidation was moderate (30%).

The sampling scheme was focused on the area around the wells and demonstrate that the methane surface emissions concentrations decline with an increase of the distance from the well (Akerman and al, 2011).

An area of approximately 0,5 ha including the tumulus of the landfill (cf. Figure 5) was choiced to treat the diffuse emissions coming near the well and along the extrados of the well, with a specific design of the biowindows (2 biorings, 12 m and 8 m diameter).

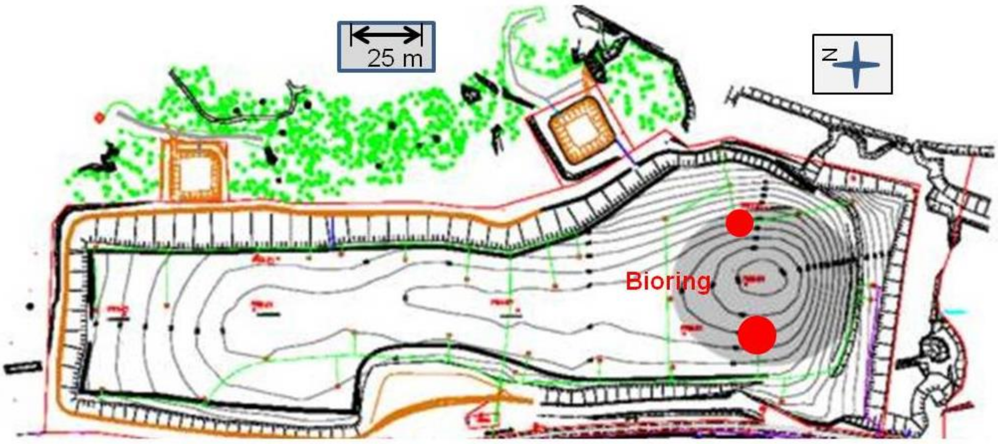

Figure 5. Location of the two specific windows (biorings) of the landfill site A . The grey area in the tumulus displays the zone choiced for the pilot scale study.

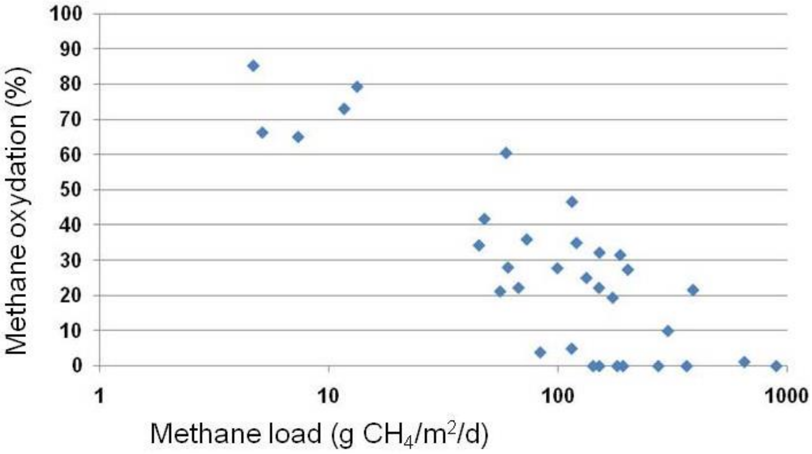

Figure 6. Initial methane load and efficiency of the methane oxidation near the collection system (vertical drainage wells) before the building of the biorings.

The specific design combines GDL (coarse sand) and a MOM composed of two matured compost layers. The deepest layer is more permeable to enable faster infiltration drainage, a facilitated diffusion of biogas and a more continuous pore distribution transition with the GDL.

In addition to the realization of devices, instrumentation of treatment devices with particular measurements including 24 soil air probes by ring and tubes for volumetric humidity TDR measurements has been implemented. These 2 biorings were monitored for one year. We observe a rapid establishment of oxidation on the two biorings.

In the case of the largest ring (12 m diameter), the total methane flow rate of the ring has varied in the range 0.1 - 1.5 m^3 CH_4/h, with about 75% efficiency for a surface load of about 2 L CH_4/m^2/h. This performance confirms data previously obtained by INERIS with a similar treatment design with a same surface load (site of Launay-Lantic).

Beyond this load, a rapid drop in the efficiency of oxidation at a rate of about 30% was observed on this ring, which seems to be continued until the surface load of approximately 10 L CH_4/m^2/h (measured on one campaign).

A total methane flow rate varying between 0.07 and 0.5 m^3 CH_4/h of methane was observed on the other ring (8 m diameter). No limit of the potential of oxidation on this ring was found, the percentage of oxidation varied between 70% and 90% on the entire range of surface load of methane explored by the measures (1.5-10 L $CH_4/m^2/h$). An efficiency of 75% of oxidation for a surface load between 0.9 and 3 L $CH_4/m^2/h$ was also observed on the perimeter of the ring. Theses devices allow to assure an efficiency of oxidation for a relatively high load in methane, and initially poorly distributed (mostly convective, due to the 'hot spots').

Confirmation of the range of the potential of treatment by oxidation (75% efficiency for a surface load of about 50 L $CH_4/m^2/day$) as well as a local improvement of the oxidation on the perimeter of the devices allows to consider this type of treatment for areas without active drainage and with low residual biogas loads.

4. RESULTS AND DISCUSSION

The parameters for the biomitigation system used on 12 french landfills using passive biomitigation systems were detailed in the Table 1. Only passive biomitigation (passive drainage and passive treatment) is presented here. A better efficiency could be achieved with active biomitigation, especially during the transition phase from active collection to after care period when the energy was still available on the site.

The total surfaces of the passive systems presented are in the range 120-512 m^2, and concern field scale projects, but the site A, site D and the site of Neuville-Les-Dames were operated as pilot scale projects : the monitoring phase was important (one year or more) and the parameters (type of the MOM,…) have been adapted during the project in order to produced more return of experience.

Two of this site are in the operation phase and landfill MSW for the site D and low organic content waste for the Launay-lantic site.

These informations are recorded from INERIS and EODD projects. The return of experience reachs 8 - 10 years for the first pilot scale projects (landfills of Launay-Lantic, Mauguio, Rimeize). LFG modeling approaches were used for the biofilter solution. On the contrary, the LFG surface measurements approache was used for the biowindows projects. The other major difference was the presence of a LFG collection for the site A and D.

The major criteria for the use of biomitigation with a biofilter are the low production estimated from LFG production modeling and the low quality of the biogas. The surface and the depth of the passive biotreatment media are linked with the methane load and the climate of the area: dried area can be found on the surface of biofilters with no artificial water addition and no sufficient raining periods (e.g. Mauguio site, located in the south of france). On the contrary, a high level of rainfall limits the porosity of the media used for the biomitigation and could generate a clogging (e.g. first cell and MOM of the Launay-Lantic landfill).

The thickness of the GDL varies for these landfills from 50 cm (Site A), 30-50 cm (site D), 30 cm (Launay-Lantic) to a thickness of 20 cm for all the passive biofilter. A coarse sand or a gravel was generally used for this layer.

The ratio between the surface of the landfill collected by the biotic system and the surface of the MOM was evaluated. This ratio must be used with precautions: the total methane oxidation efficiencies of the biotic systems combine many parameters and the efficiency was not assessed for all the biomitigation systems.

The methane load and the methane oxidation efficiency were investigated for only 2 biowindows and one biofilter. They vary respectively between 32-160 g $CH4/m^2/d$ (75 - 30%, site A) , 50-150 g $CH_4/m^2/d$ (80 - 30%, Launay-lantic site), and 50 g $CH_4/m^2/d$ (60%, Neuvilles-Les Dames site).

Two others biofilters were also investigated for the efficiency only, with a value of 80% and 50-75% for respectively the sites of Mauguio and Rimeize. These methane loads and efficiencies are is in the range of previous reported value for soils (52-102 g $CH_4/m^2/d$, Abichou and al, 2011) and landfill covers (7.2-384 $CH_4/m^2/d$, Gebert and al, 2006) for oxidation rate.

Table 1. Parameters of the biomitigation system used for 12 french landfills equipped with passive biowindows and passive biofilters

Landfill	*Area (ha)*	*MOM Type*	*MOM surface (m^2) /thickness (cm)*	*Surface ratio site/MOM*
Site A	0.5	2 layers compost	150/75	33
Site D	0.5	2 layers compost	150/75	33
Launay-Lantic	0.25	1 layer compost	120/70	21
Neuville les Dames	1.2	1 layer compost	300/75	40
Mauguio	10	Mixed	400/60-90	250
Rimeize	2	Mixed	256/120	80
Pertuis	5	Mixed	256/120	195
Le Puy Sainte Réparade	2	Mixed	256/120	80
Limoux	10	Mixed	2*256/120	195
Le Moule	1.3	Mixed	256/120	51
Saint Pierre de Trivisy	1.7	Mixed	256/120	66
Valdurenque	10	Mixed	256/120	390

The methane load varied in a large extent for the site A, but similar and even more variations have been observed (24-1200 g $CH_4/m^2/d$, Dever and al, 2011) for a passive biofilter. The maximum observed methane oxidation rate reported reached 1920 g $CH_4/m^3/d$ (Gebert and al, 2006), but on a 15 m^3 polyethylene container scale, lower than the scale of the site A (90 m^3 of MOM, surface of 112 m^2 for a 12 m diameter bioring). We can also notice that the lower bioring (8 m diameter) have a better methane oxidation efficiency: the scale effect was noticed even on this (8-12 m) scale range: the thickness of the GDL was the same for the two biorings, but the larger radius of the bigger bioring (12 m diameter) limited the efficiency of the distribution of the gas (larger gas travel distance). The sizing of the passive biowindow has to take account of this parameter.

The quality of the biogas was investigated for the 6 first sites of the Table 1. For the biowindows sites (first 3 sites), the methane percentage varies a lot during the monitoring: it varies from 5.2-52 % (site A), 12-50 % (site D) and 1-40 % (Launay-Lantic). The methane concentration of the biofilter seems more stable with values of 28-49% (Neuville-Les-Dames), 20-30% (Mauguio) and 20-50% (Rimeize). Oxygen was also monitored for the last three biofilters : 0.9-8% (Neuville Les Dames), 0-10% (Mauguio) and 10-15% (Rimeize). The first pilot scale biowindow (Launay-Lantic) has suffered from raining periods but was modified for the others cells. The optimization of the gas distribution layer (GDL) and the methane oxidation medium (MOM) can be not adequate, if the drainage is not sufficient. A slope could be integrated in the design of the MOM (Chassagnac and al, 2009) and/or in the interface of the GDL/MOM (Bour and al, 2013), in order to allow a better drainage.

One of the main return of experience concerns the type of the MOM : the organic components of a compost MOM evolve, even if the compost is matured. Also mixing compost with a more stable material (pellets, pozzolan) can improve the stability over time.

The structure of the MOM can be modified : the rising bulk density after compaction decrease the diffusivity of the MOM. A relationship between the air-filled pore volume and soil gas diffusivity was fitted (Gebert and al, 2009). As a consequence, the saturation of the MOM porosity and the compaction of the MOM must be controlled. A compaction of the compost occurs and the remaining porosity can be affected by the water saturation, limiting the diffusion of the oxygen in the MOM. Sandy materials can be used but they have also drawbacks during the summer season with the insufficient water supply for the vegetation (Groengroeft and al, 2009).

5. CONCLUSIONS

The description of criteria used for the choice of biomitigation treated LFG was discussed for 4 landfills, including detailed information about the biomitigation system used for 12 landfills. LFG production modeling was used to choose the passive biofilter and the size of the biofilters for 9 landfills, with the use of other parameters (e.g. gas quality). Biowindows were chosen for the oldest part of 2 MSW landfills and for a landfill with low organic waste content. The oxidation efficiencies were measured on 5 biotic systems. They are in the range of previously reported results.

A scale effect (a decrease of efficiency with an increase in size of the biowindows/biofilter) was observed on one site, but without confirmation on the other sites. The duration of the monitoring (more than one year) allowed us to observe a large variation in the passive methane load and methane oxidation efficiency. Due to the growing vegetation on a fraction of the biowindows/biofilters, maintenance work must be planned on different sites and can be compared with other strategy (active biofilter) for the sites equipped with a collection system.

The challenge can be the comparison of different options for the biomitigation for the long run: the combined efficiency of passive drainage and methane oxidation in a specific dedicated surface (biowindow or biofilter) need a minimum of survey which must be planned at the building of the biomitigation process, in order to limit fugitive methane emissions.

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