BIOGAS MONITORING AT THE END OF AFTERCARE PHASE ON A LANDFILL SITE IN WALLONIA

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ABSTRACT: In Wallonia, the regional legislation sets the aftercare phase of landfills at 30 years. In accordance with European Directive 1999/31/EC, at the end of this aftercare period, the landfill is supposed to be stabilized at a level causing no more adverse environmental effect.
In practice, since Walloon landfills are covered with impermeable capping after operation, leachates and biogas monitoring shows that those sites are not stabilized after this 30 years period. Moreover, the current legislation does not set objective or numerical end-of-care criteria.
In 2016, ISSeP (Scientific Institute of Public Service) started to work on the update of the Walloon legislation in order to:

- Establish and validate end of aftercare criteria;
- Allow and promote acceleration of body waste degradation via specific practices on landfill sites.

Specifically on biogas management, the principle of "prioritization of treatment methods" is applied. This principle constrains site managers to proceed to five successive steps:
1. Active biogas collection plus energy production;
2. Active biogas collection plus flare burning;
3. Active biogas collection plus alternative treatment (for instance biofilter or activated carbon treatment);
4. Shutdown of biogas collection system plus alternative treatment (passive methane oxidation system);
5. End of biogas aftercare.

Moving from one step to the next one is driven by compliance with different environmental criteria.
The landfill of Morialmé (Province of Namur, Wallonia, Belgium) is a relevant case study to illustrate the evaluation methodology. It led to the validation of the proposed criteria and monitoring method.
Full rehabilitation was carried out in accordance with the Walloon regulation and ended in 2012. However, the site was left without any biogas management since the end of waste landfilling in 2006.
In 2022, a series of investigations allowed to identify the need of appropriate management according to the biogas management hierarchy.
To validate the absence of flare burning, a pumping test was carried out. Monitoring of biogas production and composition showed that the defined criteria were fulfilled.
The absence of pumping was validated by mean of monitoring surface methane emissions. Several monitoring campaigns were carried out during different meteorological conditions. Air quality measurements also allowed to rule out sanitary risks for workers and residents in the surrounding area.
The need of an alternative treatment such as a passive biogas oxidation system is currently being evaluated.
The detailed description of selected criteria and monitoring techniques will be given, as well as the

results of the monitoring phase.

Keywords: end of aftercare, biogas management, case study, criteria

1. LEGAL FRAMEWORK

In accordance with European Directive 1999/31/EC (European Commission, 1999) and the regional legislation, landfill site owners in Wallonia have to manage biogas emissions during the aftercare phase, until waste body causes no more adverse environmental effect.

Directive 1999/31/EC, Annex I, section 4, gives guidelines to manage biogas emissions. It requires energy production or burning. A few recommendations about control procedures to be followed are also given in Annex III, section 3.

Transposition of EU Directive onto Walloon regional decree has been implemented in 2003. This legislation requires parameters and frequencies to be monitored for biogas and ambient air. It involves biogas to be valorized or burned in flares. No exemption for an alternative technique is allowed.

The decree sets a 30-year term to define the aftercare period. At the end of this aftercare phase, the landfill is supposed to be stabilized at a level causing no more adverse environmental effect. In practice, this is clearly not the case. At the end of aftercare period, emission levels from the landfill are far above those that could be tolerated by the environmental receptors. Furthermore, the legislation does not set objective or numerical end-of-care criteria for biogas management. As numerous sites are closed for decades in Wallonia, there is a need for a framework to evaluate the end of aftercare, especially for biogas management.

2. OBJECTIVES AND METHODOLOGY

2.1 Objectives

Since 1998, ISSeP, the Scientific Institute of Wallonia, periodically has performed monitoring campaigns on MSW landfill emissions (leachate, biogas,…) and their impacts on potential receptors (surface and groundwater, ambient air) on landfill sites and former controlled dumpsites in Wallonia. As a result, the Institute owns a collection of monitoring data about those landfills for more than twenty years and followed their management from the beginning of landfilling until rehabilitation and aftercare.

Those data show that, since Walloon landfills are most of the time covered with impermeable cover, stopping leachate and biogas management could still harm environment or human health after a 30 years period. In other words, this means that waste are not yet mineralized and stabilized at an acceptable level.

Especially with biogas management, site managers face the problem that the flow rate and concentration of methane in biogas decrease and become too low to burn correctly, what lead them to a violation of the current legislation.

Therefore, since 2016, ISSeP works, at request of the Walloon authorities, on the update of the Walloon legislation in order to:

- Establish and validate end of aftercare criteria;
- Allow and promote acceleration of body waste degradation via specific practices on landfill sites.

2.2 Bibliographical resources

ISSeP’s work based on numerous publications regarding end of aftercare criteria in order to choose adapted criteria and to define an adequate monitoring method.

Stegmann R. *et al.* (2006) first proposed numerical criteria to stop biogas monitoring. Active collection and treatment facilities have to continue as long as the biogas production exceeds 25 m³/h or 5 m³/h/ha of methane. Below these values, passive methane oxidation can be processed and a monitoring of surface methane emissions must be done. If the concentration is kept below 25ppm for a ten years duration, monitoring can be stopped.

In France, Ademe (2007) propose criteria to categorize landfills according to their biogas production. It also discusses the technical and economic constraints of capturing and recovering biogas.

UK EPA (2010) set up a two-steps methodology to follow surface methane emissions. First step focuses on locating emissive zones. The objectives are to not exceed 100 ppm of surface methane emissions, and 1000 ppm around collection and treatment facilities within one year after covering. Second step involves flux chamber measurements in order to quantify surface methane flux. Methane flux can not exceed 0,09 mg CH_4/m²/day. If thoses values are exceeded, corrective actions must be implemented. The monitoring is repeated annually, but there are no criteria to end the monitoring phase.

Kjeldsen & Scheutz (2015) synthetized previous works and draw guidelines about gas emissions monitoring. One of the principles set out in this paper for choosing the right threshold levels and stopping monitoring is particularly relevant. It states that the whole site methane emissions (per unit surface area) must be lower than similar surface area normalized emissions from natural ecosystems (wetlands). The article give the reference value of 1,3g CH_4/(m².day).

ISSeP gathered all the knowledge contained in those research works to adapt it in a methodology used to manage biogas emissions on landfills in Wallonia. Based on the consulted literature and the consolidated results, the Institute was able to develop its own evaluation methodology and end of aftercare criteria for biogas.

2.3 Methodology and criteria

ISSeP's propositions to update Walloon legislation aim to:

- Allow site managers to implement alternative treatments of methane emissions when flare burning is no more technically achievable (which was not possible according to the decree still in force).
- Give objective tools to authorities when they need to validate end of aftercare.
- Favor the use of acceleration method in order to faster reach a stabilized state.

Regarding biogas management, one major principle is added to current practices. It is called "prioritization of treatment methods". This principle constrains the site managers to proceed to five successive steps:

1. Active biogas collection plus energy production;
2. Active biogas collection plus flare burning;
3. Active biogas collection plus alternative treatment (for instance biofilter or activated carbon treatment);
4. Shutdown of active biogas collection plus alternative treatment (passive methane oxidation system);
5. End of biogas aftercare.

In practice, this means that gas pumping and combustion are maintained over the longest possible term by applying the best available techniques, firstly for energy recovery then by burning in a flare.

When flare burning is no longer possible (calorific value and/or insufficient biogas flow), active biogas pumping is still maintained over the longest possible term. Biogas has to be treated by devices designed to destroy methane by oxidation and at reducing VOCs emissions.

When:

- gas pumping is no longer technically achievable,
- methane concentration in biogas is no longer within the explosivity range of methane,
- other compounds (VOCs) concentrations are no more problematic for human health,
- GHG emissions deemed acceptable,

a passive degassing system (such as venting) is implemented in order to avoid any possible overpressure within the waste body.

Moving from one step to the next one is driven by compliance with different environmental criteria. This compliance must be demonstrated by monitoring data.

- From energy production (stage 1.) to flare burning (stage 2.)

There is no binding criterion for moving from energy recovery from biogas to its destruction in a flare. In France, Ademe (2007) recommends energy recovery when both criteria are simultaneously met:

  - Total methane flow > 50 Nm³ CH_4/h
  - Surface flux > 10 Nm³ CH_4/ha/h

In practice, the moment when landfill operators choose to cease the valorization is driven by economical aspects.

- From flare burning (stage 2.) to alternative treatment (stage 3.)

Combustion shutdown can only be implemented if the following conditions are met simultaneously:

  - Methane content in biogas is lower than 25% in operation or lower than 30% atrestarting biogas pumping and treatment;
  - Methane flow in the biogas is lower than 25m³/h and 5m³/h/ha;
  - Performance of the biogas collection system is demonstrated by the absence of surface methane emissions. Screening of methane concentrations on and around the site does not show a value higher than 25 ppmv.

- From alternative treatment with active collection (stage 3.) to shut down of pumping (stage 4.) To stop pumping system, three types of criteria must be achieved :
  - Methane emission: For the entire site, methane emissions are equivalent to or lower than emissions produced by natural ecosystems of equivalent surface area (wetlands assessed at 7000Nm³ CH_4/ha.year or ~20Nm³ CH_4/day);
  - Non methanic organic compounds: Flows of NMOC are lower than 34.10^6g/year for three consecutive years.
  - Air quality: Air quality criteria must be met for a range of compounds. They are measured at predefined Points of Exposure (POE), namely where human targets are spotted (residents, workers,…). Criteria are listed in Table 1 and correspond to a compilation of regional values.

Table 1. Air quality criteria at POE

Compound	Units	Limit value	Applicability
Benzene	µg/m³	50 5	P98 of daily values Annual average
SO_2	µg/m³	350 125	Hourly average (no more than 24 passes/year) Daily average (no more than 3 passes/year)
NO_2	µg/m³	200 40	Hourly average (no more than 18 passes/year) Annual average
CO	µg/m³	10	Daily maximum of the 8-hour average
PM10	µg/m³	50 40	Daily average (no more than 35 passes/year) Annual average
Vinyl Chloride	µg/m³	10 0,6	P98 of half-hourly values Walloon IC
1,2-dichloroethane	µg/m³	700 0,38	Guideline of daily average Walloon IC
Toluene	µg/m³	260 3000	QC (weekly average) IC (daily average)
Styrene	µg/m³	100 260	IC (hourly average) weekly average
Tetrachloroethylene	µg/m³	2 250	Walloon IC Daily average
Trichloroethylene	µg/m³	2	IC
Ethylbenzene	µg/m³	0,4 4	QC Walloon IC (annual average)
Xylene	µg/m³	100 700	QC IC (daily average)
Dichloromethane	µg/m³	20	IC

QC = Quality criterion achievable in one life
IC = Intervention criterion

- From passive methane mitigation (stage 4.) to end of aftercare (stage 5.)
  A control monitoring period is set in accordance between site manager and authorities. During this period, the above criteria must continuously be met. At the end of this period, the aftercare is considered achieved.

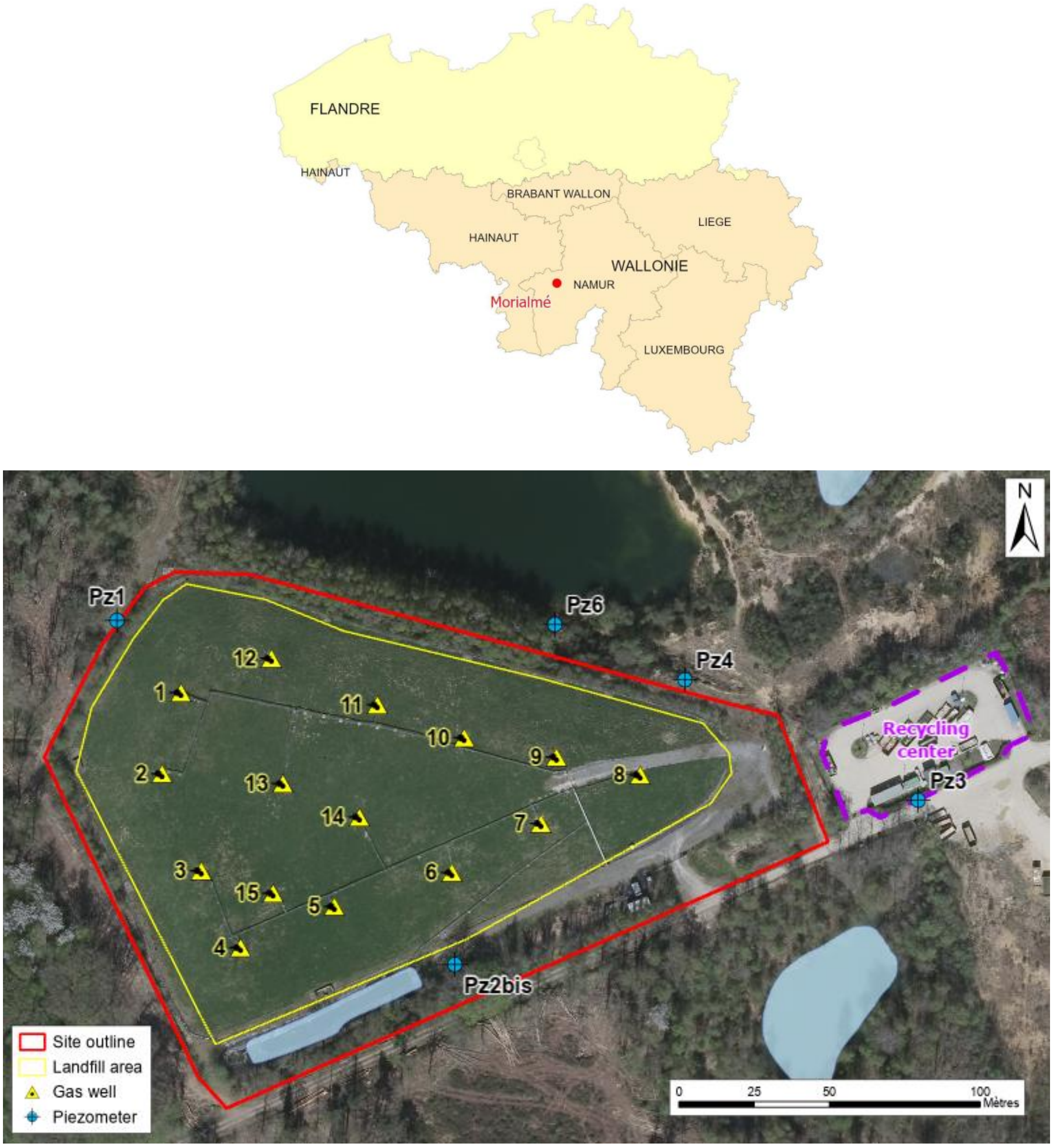
3. CASE STUDY

The MSW landfill of Morialmé (Province of Namur, Wallonia, Belgium) is a relevant case study for testing and illustrating the evaluation methodology. It has been monitored by ISSeP since 2006. The objective of the test is to validate *a posteriori* the absence of biogas aftercare regarding the established methodology. The study on this site led to the validation of the proposed criteria and monitoring method.

3.1 Site description

The landfill of Morialmé (Province of Namur, Wallonia, Belgium) was operated between 1993 and 2006. It is a former clay extraction site filled with municipal waste (approximately 270,000 m³ waste). The rehabilitation of this 2-hectare site took place between 2008 and 2010, including the installation of a gas collection network composed of 15 wells (Figure 1). However, while properly collected, biogas composition and production never were sufficient enough to keep a flare in working order. Therefore, since the beginning, the owner doesn’t meet the requirements of the regional legislation, i.e. biogas combustion. In 2022, the authorities enjoined the owner to evaluate the potential for a biogas valorization and to identify the appropriate management technique according to the biogas management hierarchy.

Figure 1. Location of the Morialmé landfill



3.2 Investigations and results

In 2022, a series of investigations were led to identify the need of appropriate management according to the recently developed biogas management hierarchy. In this specific case, the assessment aimed to check if the absence of active biogas management can be validated *a posteriori* or if active measures should be implemented.

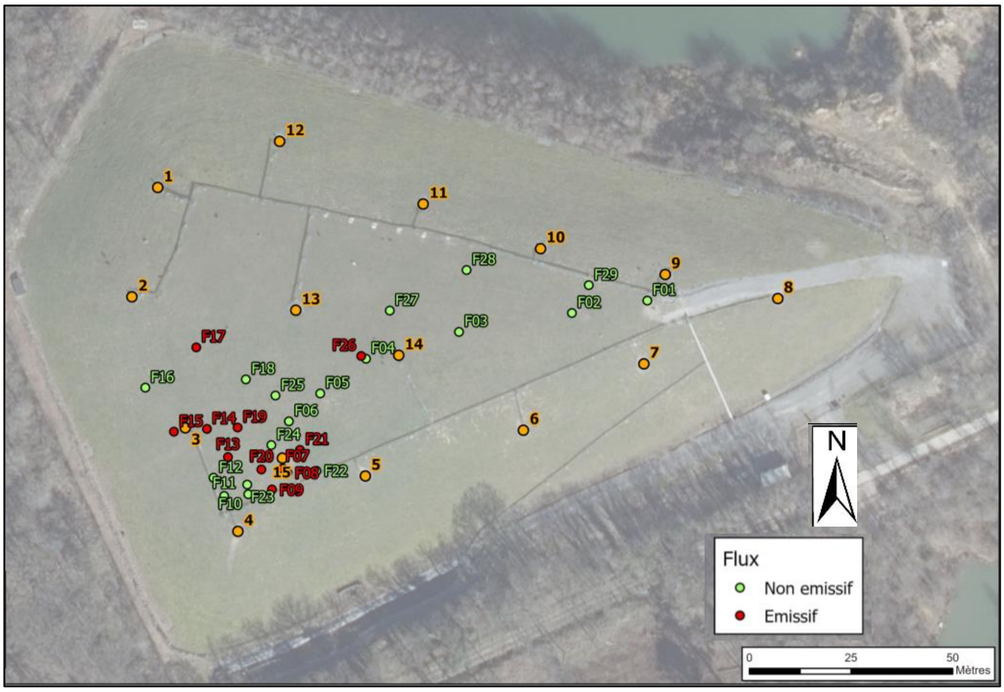
Three types of investigations were led:

- Biogas characterization: a pumping test was carried out for two month. Continuous monitoring of biogas volume and composition showed that the selected criteria to validate the absence of flare burning are fulfilled. Indeed, the average methane concentration is estimated at around 3% for an average pumping rate of around 40 m^3/h.
- Detection of methane surface emissions and flux quantification: surface measures were realized with Inspectra laser®, an infrared detector sensitive in the entire range of concentrations (0 to 100 %). During the pumping test, a surface emission screening was carried out to confirm the performance of the degassing network. It was confirmed by the absence of concentrations higher

than 25ppmv (P95 value = 3,6ppm; n = 1844).

During the absence of pumping, another screening was performed to identify and delineate emissive zones. Then, local methane flux measurements were taken with a flux chamber. A delineation of a very restrained emissive zone was obtained. Indeed, screening of 2022 confirmed previous measurements taken with the same technique in 2017 and 2018. In March 2022, methane flux measurements were realized in this delineated emissive zone (Figure 2).

Figure 2. Location of methane flux measurement points (March 3, 2022)



The flux calculation at each measurement point is based on the principle of gas accumulation in the chamber. As the increase in concentration occurs globally linearly, a local flux (F_x) is calculated, from a time series, according to the formula (1).

$$F_x = \frac{C_{ch}}{k} \times \frac{\Delta C}{\Delta t} \qquad (1)$$

Where $C_{ch} = \frac{V}{S}$, V : volume included in the chamber, S : floor surface covered;

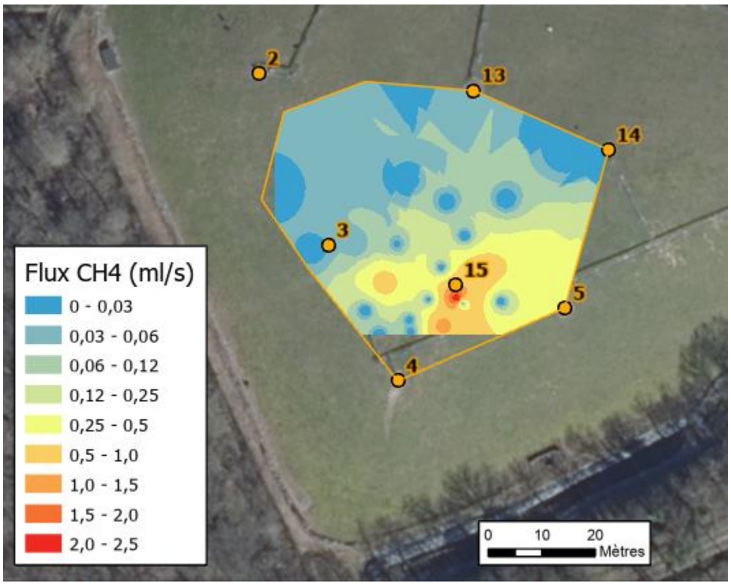
k permeability correction factor, depending on the nature of the soil and its humidity, determined experimentally. Here, it is a clay soil with low permeability. The factor used is 0,90.

$\frac{\Delta C}{\Delta t}$ concentration gradient observed during the linear part of the measurement. It corresponds to the slope of the regression line that can be calculated on the recorded concentration time series. The local flux was calculated for all the time series with a sufficient number of non-zero concentrations and for which the coefficient of determination of the regression line was greater than 0,95.

From the local flux measurements, an extrapolation is carried out to calculate a global flux for the entire site. Two different extrapolation methods were used: influence polygon, and spatial interpolation with inverse distance weighting (IDW). The results obtained with both methods lead to opposite conclusions. The influence polygon method led to a calculated flux of 11,28 m³/(ha.day) what is below the criteria to stop pumping system. With the IDW, the calculated flux is 326,88 m³/(ha.day), what is largely over the criteria and requires the installation of a pumping system and an alternative treatment (i.e. oxidative window).

In 2023, additional campaigns have been planned to confirm one or other trend.

Figure 3. Interpolation of local methane fluxes (ml/s) on the emissive zone



- Air quality control: methane concentration in surrounding of the landfill is controlled permanently. But no data about NMOC were available. Therefore, a measurement campaign using adsorbent tubes was carried out for a week in September 2022. Two stations were implemented: the first one on the landfill and the other one in the nearby recycling center. The samples were taken every day at a flow rate of approximately 50ml/min over a period of 23 hours. Results never exceeded limit values defined for air quality, except for one. Ethylbenzene exceeded intervention criterion on one day and only on the recycling center (6,21µg/Nm³). The value was associated with handling activities in the hazardous products storage area and was not related to the landfill. Since then, air quality measures allowed to rule out sanitary risks for workers and residents in the surrounding area.

4. CONCLUSIONS

ISSeP set up an evaluation method and criteria to end aftercare operations on MSW landfills. With regard to biogas management, the method is mainly based on the principle of “prioritization of treatment methods”. In 2022, the landfill of Morialmé has been monitored and evaluated according to the methodology. The gathered data were compared to criteria defined to move from one stage to another. Results showed that:

- Criteria to stop biogas burning are fulfilled: the methane content in the biogas is well below 25% and the volume flow of methane in the biogas is less than 25m³/h and 5m³/(h.ha). The performance of the biogas collection network is demonstrated by the absence of diffuse methane emissions.
- Criteria to stop biogas pumping are uncertain: air quality criteria are fulfilled, but there are still uncertainties about level of surface emissions. Indeed, depending on the used calculation method, total flux of methane for the entire site is either above or under the defined criterion (7000Nm³/ha.year or 20 Nm³/ha.day). Then, the suitability of an alternative treatment method should be assessed, with new investigations campaigns planned in 2023. Due to the absence of VOCs in biogas, activated carbon reduction is not relevant. A biofilter system could be considered but performance is rather average and fluctuating and proves to be costly compared to expected benefits.

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