DESIGN, CONSTRUCTION AND MONITORING OF A PASSIVE METHANE OXIDATION BARRIER PLACED IN THE CAPPING OF A LANDFILL FOR HAZARDOUS AND NON-HAZARDOUS WASTE

Extended abstract

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Background

The landfill final capping, besides ensuring the isolation of waste from the external environment and the minimization of water infiltration and erosion, can be integrated with elements aimed to the emission attenuation of biogas into the atmosphere, especially against methane. These systems, which are called Passive Methane Oxidation Barriers or biofilters, find their best application in those landfills where biogas recovery is not technically or economically feasible. An analysis of the experiences already made shows the possibility of designing passive barriers in different ways with each other resulting in the achievement of different treatment efficiencies.

Following a study on biogas management for a landfill site, located in Ravenna Via Romea Nord km 2.600 and managed by SOTRIS S.p.A., it was observed that the 3rd operational phase landfill for hazardous and non-hazardous waste is characterized by the production of low quantities of biogas mostly resulting from fermentation processes taking place in redox conditions. The results showed that the quality and quantity of biogas produced by the landfill does not allow any exploitation or justify the need for additional forms of collection. It was, however, assessed the need for a not substantial modification of the landfill final capping, in order to realize a treatment system capable of adequately handling the volume of biogas emitted by the landfill body.

This article then outlines the design choices made for the passive oxidation barrier that consists of a two-stage oxidation biofilter realized by mixing different percentages of fine rounded gravel and composted green soil. The article also explains the installation modalities (mixing of materials, methods of installation), the operations provided for maintaining the passive oxidation barrier and the arrangements for renewal of the barrier including the management of exhaust substrate. It also describes the monitoring activities and the instrumentation designed for the study of treatment efficiency of the barrier and for the analysis of gaseous species that this system is capable of treating.

Introduction

The study on biogas management, realized in July 2008, shown that the 3rd operational phase landfill for hazardous and non-hazardous waste is characterized by the production of low quantities of biogas with a specific flux emitted approximately 0.9 - 1.6 l/m²h (values obtained with the dynamic accumulation chamber method as a result of a measurement campaign of the flow of biogas emitted from the surface).

The chemical and isotopic analyzes conducted on samples, collected from gas wells present on the landfill, highlighted the lack of relevance of fermentation processes of organic material, typical for MSW landfill. Prevail instead processes that occur in different redox conditions, generating a gas generally poor in methane (average concentration lower than 20% in volume).

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1. Passive oxidation barrier dimensioning

The passive methane oxidation barrier has the following general characteristics, as well as visible in Fig. 1:
- it is positioned on the top of the landfill, presenting a thickness varying between 1.0 m and 1.2 m;
- it has 4 “biogas supply screens”, produced below the barrier directly in the HDPE geomembrane; these areas have almost rectangular shape with sides approximately 25 x 10 m for a total area of 1000 m²;
- the oxidant section presents almost rectangular shape with sides approximately 25 x 60 m for an overall planar development equal to 1550 m².

![Figure 1. Schematic plan of 3rd phase landfill with identification of biofilter boundary and supply screens](image)

The following is a detailed description of each element that constitute the final capping of the landfill, in vertical succession from bottom to top, with particular reference to the oxidation barrier. This succession is observable in the section illustrated in Fig. 2:
- leveling layer: its function is to allow the proper installation of the overlying layers; it is realized with variable thickness soil;
- biogas drainage layer: it performs the double function of conveying leachate to the bottom and convey any biogas side emission towards the top part of the landfill in which there is the barrier of oxidation;
- low conductivity barrier: it consists of a HDPE geomembrane coupled to a bentonite geocomposite that cover the entire surface of the landfill. On the top portion of the landfill there are four "supply screens" with dimensions 25 x 10 m, covering a total area of 1000 m² (Fig. 1) obtained removing rectangular elements of geomembrane. These windows are the feeding areas of the passive oxidation barrier realized on the top and will then allow the upward migration of the flow of biogas originating from the waste body. It is, however, necessary to ensure that the cover system does not permit the infiltration of rainwater inside the waste body. To this end, in correspondence of the areas without geomembrane, the capping has been integrated by installing a second bentonite geocomposite that goes to entirely cover such areas (including an adequate overlap with the underlying geomembrane for about 1 meter of the overall perimeter);
- rainwater drainage layer: prevents the formation of a hydraulic head above the impermeable barrier, evacuating rainwater filtration that will affect the top part (biofilter) to the discharge system. This element is also the first homogenization horizon, uniformly distributing the diffusion of biogas below the oxidant barrier.

The final element of the landfill capping system is the passive oxidation barrier. This has been structured in vertical succession with two biofilters with different characteristics between them and separated by an intermediate drainage layer, as illustrated in Fig. 2. The elements that constitute the passive oxidation barrier are (from bottom to top):
- planar gravel drainage, thickness of 10 cm: this element, in addition of increasing the rainwater drainage efficiency is a further homogenization horizon of the biogas flow out of the waste body. It is also functional to the maintenance of the biofilter, preserving from damaging underlying elements during the regeneration phases of the barrier (consisting in the removal of the exhausted substrate and replacement with fresh material);
- first oxidation stage: 50 cm of thickness, made with a mixture consisting of 30% organic substrate and 70% inert material (percentages by weight); having a measured a density of 0.6 t/m³ for the organic substrate and 1.6 t/m³ for the gravel, the volume ratio is 1,2:1. This first stage is characterized by a higher percentage of solid skeleton, compared to the next stage, in order to avoid compaction phenomena once subjected to the load of the upper stage, and allow the air migration to deeper layers ensuring an adequate intake of oxygen necessary for the oxidation processes;
Design, construction and monitoring of a passive methane oxidation barrier placed in the capping of a landfill

- intermediate drainage geocomposite: this element performs the dual function to redistribute the flow of biogas output from the first oxidation stage prior to its entry into the second stage; also facilitates the circulation of ambient air toward the first stage of oxidation;
- second oxidation stage: variable thickness 50 ÷ 70 cm: made with a mixture consisting of 40% organic substrate and 60% inert material (percentages by weight); with the same density considered previously we get a volume ratio of 1.8:1. This stage has a higher percentage of organic substrate, in order to achieve a higher efficiency of treatment and facilitating the plant vegetation.

Fig. 2. Schematic section of the oxidation biofilter

2. Passive oxidation barrier construction

The constituting materials of the barrier must have the following characteristics:
- the inert material consists of rounded gravel with a grain size d 5 ÷ 10;
- the organic substrate is made of green composted soil that has the characteristics set out in Annex 2 of Legislative Decree no. 75 of 29 April 2010 (Italian legislation).

The mixing of these materials was carried out prior to its installation, using a suitable machine for mixing (like a cement mixer). Adequate quantities of the two materials were taken in such proportions to respect the weight ratio previously specified and differentiated for the two oxidants stages. The installation of the mixture occurred without any type of compaction but simply leveling the substrate to achieve the required thickness. Considering also that the construction operations for the second oxidant stage were held above the first stage and that the quantities of material to be handled are contained, the machine used for the realization of the barrier was a small size excavating, in order to ensure the minimum level of compaction on the lower layers.

In order to ensure full treatment efficiency for the passive barrier it is assumed to regenerate the biofilter with appropriate timing of intervention. These operations, consisting in the removal of the exhausted material and reconstitution of the oxidant barrier, have multiple purposes:
- ensure the regeneration of the organic substrate, partially used in the bacteria metabolic processes, which over time will tend to deteriorate;
- restore sufficient porosity of the materials that over time have undergone a natural compaction with consequent system efficiency loss.

For these reasons, it was expected a theoretical restoration of the barrier approximately every ten years. This intervention is anyway made according to the results obtained from the monitoring of the barrier oxidation efficiency.

All the material generated from barrier maintenance operations may be subjected to a Soil Washing treatment, with the aim of recovering the fine fraction of the substrate constituted by the inert matrix present in the mixture. This process will ensure the dissolution of the organic substrate in the aqueous extraction that will later be sent to normal purification processes. The inert material recovered can be directly reused for the construction of new oxidation stages.

3. Passive oxidation barrier monitoring

The monitoring plan and instrumentation designed for the study of the treatment efficiency and for the analysis of gaseous species that this system is capable of processing is illustrated in Table 1.

In particular, the analysis of fugitive emissions of biogas is carried out with the dynamic accumulation chamber method on a mesh sampling of 5.0 x 5.0 m (for a total of 125 points). The oxidation efficiency monitoring were made by measurements and sampling directly inside the barrier as well as in deep biogas wells. To this end, specific probes were designed: each sampling point is constituted by a battery of five probes which allow monitoring
of the biofilter at various depths from the ground level: 0.2 m, 0.4 m, 0.6 m, 0.8 m and 1.0 m. There were a total of 3 installed sampling points (North, Central and South) for a total of 15 probes.

### Table 1. Methods and frequency for oxidation barrier monitoring

<table>
<thead>
<tr>
<th>Object of control</th>
<th>Parameters / Methods</th>
<th>Frequency</th>
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</thead>
<tbody>
<tr>
<td>Biogas diffused emission from landfill body</td>
<td>Accumulation chamber method (CH\textsubscript{4} and CO\textsubscript{2})</td>
<td>Annual</td>
</tr>
<tr>
<td>Biogas analysis for assessing biofilter efficiency</td>
<td>Moisture content, temperature, pH, O\textsubscript{2}, CH\textsubscript{4}, CO\textsubscript{2}</td>
<td>Half-yearly (first 3 years) then annual</td>
</tr>
<tr>
<td>Biogas analysis for assessing oxidation process efficiency (inside landfill body and in surface of the landfill top)</td>
<td>O\textsubscript{2}, CH\textsubscript{4}, CO\textsubscript{2}, CO, organic and inorganic compounds</td>
<td>Half-yearly (first 3 years) then annual</td>
</tr>
</tbody>
</table>

### Results and discussion

Data of the monitoring carried out are available for about two years. In August 2011 and February 2012 were realized campaigns for diffused biogas monitoring in atmosphere with the accumulation chamber method. The target is to quantify the total flow of biogas emitted from the biofilter and, consequently, to estimate the amount of CH\textsubscript{4} and CO\textsubscript{2} emitted daily from the top of the landfill and then check the efficiency of the biofilter. The survey showed generally negligible flow of methane and medium-low values for carbon dioxide. More than 90% values of Methane detected were below the detection limit of 0.3 ppm s\textsuperscript{-1} (corresponding to 1.6 g m\textsuperscript{-2} d\textsuperscript{-1}), while with regard to the Carbon Dioxide about 10% values resulted below of the detection limit of 0.1 ppm s\textsuperscript{-1} (corresponding to 2.2 g m\textsuperscript{-2} d\textsuperscript{-1}). The outflow from the biofilter, calculated only for the carbon dioxide because of the small number of useful measurements for methane, is approximately 5.0 Nm\textsuperscript{3} h\textsuperscript{-1} (corresponding to about 3.3 Nl m\textsuperscript{-2} h\textsuperscript{-1}). The data confirmed a good performance of the oxidation biofilter which tends to reduce the emission of biogas produced by the landfill.

With regard to the field measurements made using the measuring probes specially designed and implemented, the results show that the deeper horizons of the biofilter present low concentrations of oxygen (never equal to zero), which is used by the bacteria for metabolic processes. Oxygen levels recorded in the barrier are otherwise considerable over the entire vertical: this is essentially due to the adequate permeability of the barrier that allows the oxygen to spread effectively even at greater depths. Everywhere it is also present an increasing temperature profile with the depth associated with an increasing gradient of carbon dioxide, which demonstrates the presence of bacterial respiration. In all survey points and in each measurement campaign the methane content at the surface is null result.

As regards for the chemical analysis carried out on biogas collected samples, the analysis of the results show that in general the considered compounds have decreasing profiles proceeding towards the surface of the landfill. In particular, the concentration of methane diffusing from the barrier is substantially zero over the entire surface analyzed. The results show that the barrier reduces over 80% of the emission of BTEX (in particular for Toluene, Ethylbenzene and Xylene) than that for ammonia and Tetrachloroethylene. It is not recorded the presence of odour compounds (hydrogen sulphide and mercaptans). Nitrogen concentrations are high enough in relation to a significant presence of such compound in the biogas produced from 3\textsuperscript{rd} operational phase landfill connected to redox processes taking place within the waste body. There is also an increase of HCl starting from the bottom of the biofilter to the outside; this situation can be attributed to the aerobic cometabolic biodegradation of compounds containing chlorine (CVM, tetrachlorethylene, trichlorethylene) based on the presence of reactions on hydrocarbons (methane in particular but also BTEX) as substrate.

### Concluding remarks

The designed passive barrier is currently able to handle the volume of biogas emitted from the waste body. The flow emitted (less than 3.0 Nl m\textsuperscript{-2} h\textsuperscript{-1}) is characterized by values of methane almost zero over the entire surface of investigation. There is a more substantial emission of carbon dioxide as a product of the oxidation process.

The measurements carried out within the monitoring probes show typical profiles of oxidative processes realized by bacterial organisms. The design and construction of the barrier has allowed the achievement of significant levels of oxygen over the entire vertical even at the greatest depths.

### Keywords: barrier, biofilter, capping, methane, oxidation

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