Air pollution treatment in modern segregated waste treatment facilities

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Abstract: - The integrated waste management systems are designed to organize their waste streams, methods of collection, treatment and disposal, with the goal of achieving environmental benefits, economic optimization and social acceptability. In this perspective and in order to match European requirement, an integrated approach to environmental impact related to waste management must be implemented, taking into account every possible impact factor and, therefore, air quality and odor control should be regarded as a major concern, as directly affecting quality of life of both workers and people living in the surroundings of waste treatment facilities. A modern segregated waste treatment plant was taken as a case study to prove the effectiveness of a biotechnological treatment constituted of stand-alone immobilized cell bioreactors working on motion of contaminant for concentration gradient and not through ventilation, providing a sustainable alternative to traditional air treatment techniques. The preliminary phase of application for the system, presented into this paper, was preceded by a completion of analysis of air quality baseline, collected by a Wireless Sensor Network, which have been compared to the following three months of system activity, showing a consistent effectiveness in air pollutant containment and abatement.

Key-Words: - **Sustainable waste management system, Indoor Air Quality, Odor control, Immobilized Cell Bioreactors**

1 Introduction

The approach of the European Community with regard to waste management is based on the following principles:
- Prevention;
- Recycling and reuse;
- Final disposal and related monitoring.

Technologies related to disposal phase, as well as recycling, are to be understood in the wide framework of an integrated approach to all stages of waste management in order to ensure adequate protection of health and environment[1].

The integrated waste management systems are designed to organize waste streams, methods of collection, treatment and disposal, with the goal of achieving environmental benefits, economic optimization and social acceptability.

A proper integrated management of municipal waste analyzes the entire life cycle of waste, from cradle, corresponding to the time when a product becomes a waste, to the grave, i.e. the final stage of disposal or recycling, through which waste ceases to be such and come back as a resource. It is, therefore, clear, on the basis of the Waste European Directive that recovery technologies must be encouraged, in particular by encouraging selective collection of municipal wastes. In fact, the collection phase plays a major role in the integrated waste management system, as it allows to promote recycling operation necessary in order to substantially reduce pollution, energy and raw materials consumption, together with waste production in a cost-effectiveness, efficiency and environmental protection perspective[1]. In order to match European requirement, then, an integrated approach to environmental impact related to waste management must be implemented, taking into account every possible impact factor during the entire life cycle. As suggested by many authors, waste treatment facilities, from landfill to incineration, may be associated with emissions of air pollutant, negatively affecting air quality in the surrounding areas [2]. Even if municipal waste sorting and crushing plants carry a minor to negligible risk in

terms of threat to public health, generating an amount of contaminants (both gases and particles) lower by orders of magnitude when compared to, for example, incinerators, they nevertheless may represent a source of disturbing odor and air quality-related operational risk for employees, as air contaminants can be a major source of respiratory diseases.
In Europe, together with chemical deodorization, biofiltration is by now a well known and widely used technology for control of odors, air pollutants and volatile organic compounds (VOC - often related to disturbing odor issues) from different sources in industrial and public service sectors [3], but it remains difficult to apply, especially in urban area, because of the wide surfaces required and possible lowering in performance due to climate condition.

2 Problem Formulation

It is well known that odor problems related to waste management system may originate from airborne or surface contaminants (i.e. bacteria and fungus growth, spores, chemical fumes or digestion vapor), so that a genuine health concern accompanies odors, even when intermittent or deriving from segregated waste treatment facilities, where organic fraction should be absent. Therefore, odor control remains one of the most significant challenges for waste treatment facilities today, even if materials come from segregated collection.

Since disturbing odor are usually caused by compounds with low odor thresholds, off-gas concentrations will often be in the low ppmv range[3], making their abatement rather difficult or very expensive, both under an economical and environmental perspective. Air treatment, in fact, requires a great amount of energy, especially when dealing with piped air. In addition to this, air extraction and ducting (similar to Pump-and-Treat system used in soil and groundwater remediation field), which is the most common technique applied for air treatment, do not guarantee problem solution, since odor are often carried by fine and ultrafine particulate, as well as by gases.
As the efficiency of odor and air pollutants treatment system in waste treatment facilities is widely regarded as unlikely to be sufficient for some volatile organics, more reliable tools are needed, in addition to commonly used technologies or in their replacement, in order to reduce such recalcitrant contaminants [4].
A modern segregated waste treatment plant was taken as a case study to prove the effectiveness of a biotechnological treatment working on motion of contaminant for concentration gradient and not through ventilation, providing a sustainable alternative to traditional air treatment techniques.
The waste treatment plant selected for the trial will be treated for 15 months with Immobilized cell Bioreactors, commercially known as AIRcel system, for the containment of odor problems alleged by the neighborhood and microbiological hazards possibly carried on wastes. Both issues are closely linked to the type of work performed within the facility, even thought former air quality checks have shown that the plant is compliant to regulations for healthcare in workplaces. The company involved into the test has shown, however, interested in establishing a new standard of environmental quality within their facilities in order to prevent health and environmental risks both for workers and population living in nearby areas.
The effectiveness of the experimental application in terms of reduction of airborne contamination (gaseous, odorous and microbiological) shall be evaluated by monitoring performed by an accredited third party laboratory, a continuous wireless monitoring station and evaluation of the attitudes of people about the trend of odor emissions from the plant.
The preliminary phase of application for the system, presented into this paper, was preceded by a completion of analysis of air quality baseline: the control units (commercially known as U-Monitor) have been, in fact, installed the previous week the bioreactors system was set. The definition of the baseline was carried out during one week (July 14 to 20), excluding the first 3 days of installation (11-13 July), which showed high concentration values so abnormal compared to following days, and considered, conservatively, not significant for the construction of a term of comparison. The baseline is, therefore, been detected in a period of decreasing activity, up to the stop, of the plant for summer break.

2.1 Performance test

A precisely scheduled monitoring plan has been developed, as to cover the whole experimental period, i.e. 15 months after its inception, during which a continuous monitoring system will be kept

operational and lab analysis, such as column air test for gases and odor and Petri plates count through Surface Air System sampling, will be repeated on a seasonal basis as a complement and countercheck. In order to reproduce as faithfully as possible the boundary conditions, the production cycle will be reconstitute, from time to time, very similar to the baseline.
During the technical inspections, spot measurements were made of Volatile Organic Compounds by PID (handheld photoionizer) which, although not bearing an absolute probative value, had completed the perceptual impressions collected. This kind of portable device, in fact, is a broad band detector, calibrated on using isobutylene, and other analytes may produce a response depending on concentration. Being not selective (it may virtually ionize every compound with an ionization energy less than or equal to the lamp output) and sampling on an instant basis, this monitoring method has not been taken into account as a reliable performance test for the system.
In order to have continuous feedback on the effectiveness of the bioreactor system installed, two monitoring stations have been places in different location of the treatment facility (supply station and secondary shredder), equipped with a set of sensors that can detect a variety of contaminants, as well as explained in the next section.

2.1.1 Monitoring System

The monitoring system consists of a Wireless Sensor Network (WSN), designed to collect air quality data in the environments where the bioreactors are installed, and a software platform that is the control center, processing and visualization of the data collected.
The objective of the monitoring devices is to detect the presence of harmful gases and fine dust into the environment and, optionally, some environmental parameters, such as temperature and humidity.
The monitoring devices, physically realizing the WSN, are characterized by:
• sensors for the detection of
- temperature
- humidity
- environmental contaminants (mainly toluene (C6H5CH3), hydrogen sulfide (H2S), ethanol (CH3CH2OH), ammonia (NH3)
- solvent gases (mainly alcohol, solvents, hydrocarbons, VOC)

• particle counters PM1 and PM2.5
• built-in WiFi module for wireless and real time communication of data
• time of collection of environmental data set to 15 minutes.

2.1.2 Baseline definition

The definition of the baseline of comparison is critical for evaluating the performance of the system. This baseline has, in fact, to include a sufficient number of days to constitute a proper statistical basis for the calculation of an average that can be representative of the period and the activity of the plant. The combination of the trial with the decrease in physiological activity of the plant for the summer necessitated a proper assessment of this aspect, but it was regarded, nevertheless, as a great opportunity to relate operational phases of the facility to air pollutant concentration, during this preliminary study.
Since the very first days of application of the monitoring system showed a significant gap in high concentration of all sensors, they have been discarded and the more representative trend displayed in the following week was assumed as baseline value.

AVG values	Air Contaminant	Solvent Gas	Dust (1-2,5 micron)
Supplying	84 ppm	65 ppm	2341 part/dm3
Secondary Shredder	52 ppm	63 ppm	1820 part/dm3
Whole Facility	68 ppm	64 ppm	2080 part/dm3

Table 1. Baseline values

Evaluation of the data collected so far by the U-Monitor can not ignore the contextual consideration of production trends, as the baseline definition period and the installation of the bioreactors system took place during summer, when waste treatment proceeds in a cycle far different from the standard. At the same time, summer months, in the previous year, proved to be a critical period for disturbing odor emission, probably related to longer rest of residual material into storage tanks and anaerobic conditions establishing into them, giving space to sulfur compounds to develop and spread out.

3 Problem Solution

The air treatment system proposed to try to improve air quality standards into the waste treatment facility is constituted by stand-alone Immobilized cell Bioreactor, carefully sized and placed in order to empower the system effect and overlap influence area of the single units. No exhaust air pipeline has been installed, since the AIRcel system works on indoor containment of contaminants, preventing issue typically related with air ducting, such as high energy consumption for ventilation and air conditioning and difficulties in capturing pollutant which may be more affected from electrical surface field rather than air motion, because so fine that specific surface is overwhelming compared to mass and volume.

3.1 Technology applied

The system is based on stand-alone bio-oxidizers that provide internal air-mixing within the facility and capture particulates and gases by attracting them to a clean air zone generated by its action. The leading mechanism is the biological digestion of the hazardous materials attracted. These miniaturized treatment plants, in fact, utilize bio-oxidation to destroy gases, volatile organic compounds (VOCs), odors, and remove particulates though bio-hygienics principles, i.e. the natural phenomena used to control IAQ, electrical as well as biological[8], thus airborne contaminants are first captured and subsequently digested biologically. Intimate gas-liquid mixing with electrically grounded water from the reservoir tank additionally grounds the clean air zone, attracting and capturing pollutants. Contaminants, along with the odors that they generate, are attracted to this clean air zone by concentration gradients (pollution moves from high to low concentration, both with mass and electrical charge), where the charged particles are removed by electrical grounding and the organic compounds are oxidized [7][9][10].

This can be accounted as a sustainable technology, particularly when compared to standard air treatment systems, since it does not require elevated temperatures (as post-burners) or pressures (as membrane filters) or excess energy (as any ventilation system) to operate.

3.2 Results and discussion

The evaluation of the data collected by monitoring system has been divided between gaseous contaminants and particulate matter, which present different behaviors both in chemical and physical terms.

In order to provide an effective comparison between the contaminant concentration found during the first three months of the trial and what obtained as a baseline, some graphs are displayed in the following pages. In particular, results returned by the sensors "Air Contaminant" and "Solvent Gas" are reported first, as more closely related to the odor quality of the environment.

3.1.1 Gaseous contaminants

It is immediately evident how the system has responded to the initial saturation condition with expected developments of airborne pollutant concentration, the interpretation of which can not, however, be abstracted from the evaluation of operational condition of the waste treatment plant:

• initial increase in the concentration of the contaminants monitored, although the peak contained 80% of the baseline value (Fig. 3), corresponded with the delivery of particularly smelly waste material. The highlighted peak is detectable in both monitoring stations (as shown in yellow in Fig. 1). This event has come to engage on the phase of desaturation of the system that could not be still able to immediately treat the emergency;

• subsequent decrease of the concentrations of airborne contaminants, with a similar trend found by two different sensors and in the two positions of detection;

• secondary peak concentration (also highlighted in yellow in Fig. 1) detected during the second week of operation, performance from a side corresponding to the working phase of the system on the contamination immobilized on surfaces. This event, which tends to momentarily increase the concentration of pollutants in the indoor environment, has occurred concurrently with the occurrence of some maintenance issues on the machines.

• the next two peaks (highlighted in Fig. 1 with red arrows) detected by the sensor "Air Contaminant" at the Feeder and have been related to maintenance work on the bioreactors, which required the stop of the air treatment system.

• concentrations are subsequently dropped, despite the recovery in the plant full capacity at the beginning of September: during the first 40 days of

operation of the plant at full capacity, the airborne contamination continued its downward trend now that the system reached a state of equilibrium that allows the containment of pollutant events within a very short time;

• the concentrations found in the last weeks taken into account for the present preliminary analysis are maintained within 15% of baseline values, with a consequent reduction greater than 85% detected by both sensors.

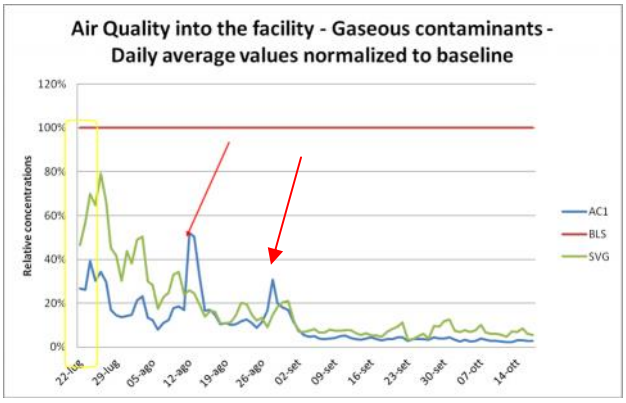

Fig.1 - Daily avg values referred to baseline value, gaseous contaminants

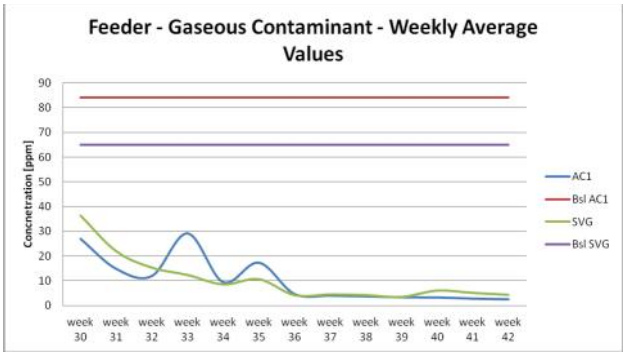

Fig.2 - Weekly avg values, gaseous contaminant at the feeder section

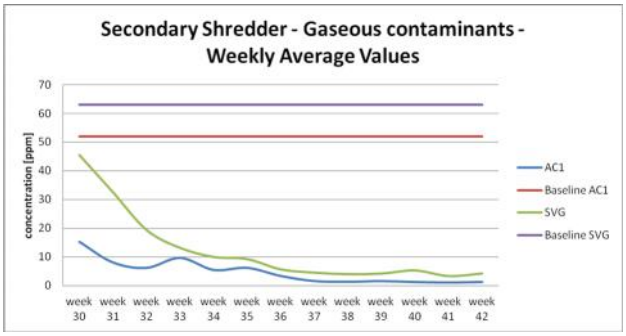

Fig.3 - Weekly avg values, gaseous contaminant at the secondary shredder section

Relating concentration peaks detected by sensors with indication of intense or disturbing odor event recorded by workers (note that no odor events has been reported by peope living in the surrounding area), it can be considered that they proved to be related to gaseous concentration peaks detected at the feer section, while no correspondence were detected with secondary shredder activity.

The peaks of gaseous contamination appear to be wider (so, longer lasting) and with a higher absolute value during the frst weeks of Bioreactors system application (July and August). During September, on the contrary, the peaks of contaminants are tighter (i.e. "shorter" in time) and reach an absolute value greatly reduced (6-8 times) than in previous months.

This trend shows that, following a first period of de-saturation (July and August) in which a large amount of contaminants (high peak values) travels slowly to the AIRcell system (broad peaks), after nearly two months of operation (September), contaminants move in small clouds (peak values slightly higher) that are attracted quickly toward AIRcell (narrow peaks) and do not spread into the surrounding environment.

The absence of abnormal measurements on device Secondary Shredder, attest that the AIRcell can capture and remove contaminants that generate odors, preventing its spread to areas far from the source.

3.1.2 Particulate matter

The contamination related to particulate matter, perceived as "fine dust" characterizing the indoor air, has been detected in parallel with the gaseous contaminants already presented. In order to give a consistent interpretation of the results a few considerations are needed:

- The particulate contamination is necessarily influenced by the activity of the plant, since it is generated by the operations of opening the waste balls and consequent shredding of the waste for final sorting, alternated to moment spent cleaning of the conveyor belts, which, therefore, must be emptied and production line stopped. For this reason, the evaluation of the performance should be carried out in parallel with production notes provided by the Company and, in particular, it is necessary to divide the consideration of two different periods:

1. summer, characterized by partial and intermittent activity of the plant, with delivery of materials, waste treatment and maintenance works when needed (July 22-August 30), as demonstrated by the different baseline values encountered (higher for feeder section, rather than secondary shredder area);

2. autumn, with recovery of full time production of the plant (September 1 to October 17);
- particulates tend to move in the air in eddies and clouds with a different degree of concentration, rather than distribute evenly in the environment;
- the two areas where monitoring stations have been installed are characterized by very different work load of suspended particulate matter: while the burden on the feeder section is related to input of the vehicles and the opening of the "bales" of waste delivered, the secondary shredder undergoes waves of contamination from two possible sources:
1. the proper shredding activity
2. the cleaning of the conveyor belts by means of compressed air, carried out at time intervals dictated by the conditions of the same belts.
These issues explain a trend of concentrations quite different from what revealed on gaseous contaminants and it is crucial to consider separately the two monitoring stations.

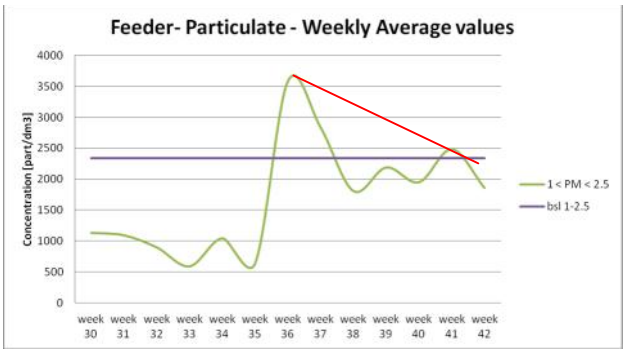

Fig.4 - Weekly avg values, particulate matter at the feeder section

The first five weeks of AIRcel system activity are characterized by a reduction of particulate contamination in correspondence to the feeder section of the plant, as shown by weekly average values, which are below 40% of the baseline. Since the levels of operation of the plant have been kept low and close to the total rest in the period of the definition of the baseline and in the subsequent weeks, it can be stated that the system contained the contamination present in the plant during those weeks.
The only peaks that exceed the baseline value are so explainable:
- 07/29/2014 peak: maintenance of AIRcel units after two days of alarm due to a high load of dust which covered the air outlet, evidenced by the remarks quoted in the production notes. At the same time, the plant has been running for two shifts on July, 24th and 25th and one again on 28th;
- 08/05/2014 peak: maintenance of AIRcel units in the days immediately preceding it.
In correspondence of waste treatment plant coming back fully operational on September 1st, a peak concentration of particulate matter has been detected, due to the re-suspension of material trapped in machinery remained steady for weeks and the increase in the pollution load carried by the shredding of waste. During the following weeks, the peaks tend to decrease, returning to fluctuate around the baseline values at the feeder section. This corresponds to a satisfactory result in containment of dust contamination, since particulate concentrations are back to a diminishing trend, albeit in full operation of the plant, towards values that characterized a period of progressive switching off of the same and the peaks are progressively decreasing (red line).

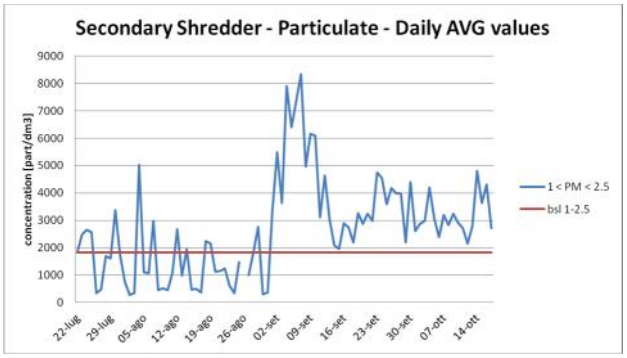

Fig.5 - Daily avg values, particulate matter at the secondary shredder section

The area of the secondary shredder is evidently of more complex management (note that the facility is an open space, with no sects deviding operating sectors), since the very nature of the processing, which tends to re-suspend periodically dust and particulate matter (even those deposited on the surfaces by gravity). Since the baseline has been defined in a period of partial processing inside the plant, values lower than the ones detected at the feeder section were provided for the same period; in contrast, the resumption of activities has meant that the peak concentrations are higher in this area, although chronologically corresponding to those already tested at the feeder (even during the shutdown, i.e. July 29th and August 5th).
The direct dependence from the operating schedule, or cleaning activities, is reflected in the performance of the most jagged peaks of concentration in daily average concentration (Fig.5). Over the forthcoming months, it will be determined the degree of correlation between these peaks and the cleaning of

conveyor belts, in collaboration with the company, which is required to keep track of cleaning activities, as has been done for the production.
The line drawn in green color in Fig.6 shows how the concentration peaks are progressively decreasing, to demonstrate containment performed by the system even in conditions of full operation of the plant.

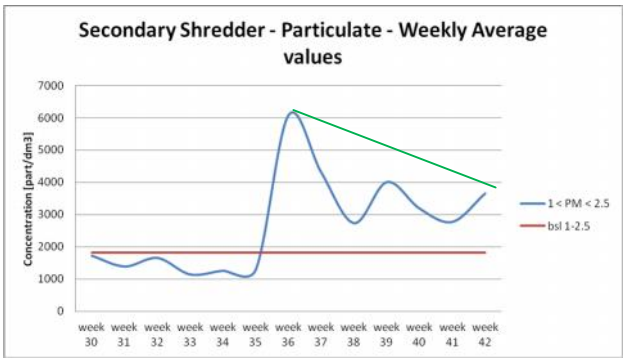

Fig.6 - Weekly avg values, particulate matter at the secondary shredder section

3.3 Overall considerations

To complete the evaluation of the data collected, perceptual aspects has been taken into consideration, being directly related to the conditions of odorous contamination and, in addition to correlations made in the previous paragraph, impressions of the facility's staff and complaints from the local residents have been recorded and it is inferred what follows:
1. since the summer, reported as critical for odor conditions for the surroundings in previous years, no alert for malodorous emissions has been reported. It can be considered as a preliminary, but crucial achievement of containment of airborne contamination. The summer period, in fact, is a critical time for the odor emissions on the one hand for weather and climate reasons (high temperature, in fact, promotes anaerobic digestion of residual waste), and secondly, due to the slowing down, until the total stop, of the plant activity. This operating mode favors the establishment of anaerobic conditions within the storage tanks of the residual material and, consequently, the development of anoxic sulfur compounds (eg hydrogen sulphide) with low odor threshold and, therefore, potentially disturbing in smell;
2. the staff notes that the smell is still present within the facility, related to the input of particularly odorous material and its processing, but at the same time, it tends to not propagate outside. This configuration corresponds to the action of the containment principle established by AIRcel system around the source of contamination and it is reflected in measurements provided by portable photoionization detector (PID), which detected
2.1 fluctuating values of volatile organic compounds within the plant, related to the nature of snapshot surveys the device performs, which appear to be less effective in open environment;
2.2 a decrease of the same values at the chimney, where the flow of air conveyed by local extractor makes the measurements more constant in time and, then, reliable, as far as possible: this data confirms the impressions of the staff and corresponds to the expected behavior of the contaminants, which are attracted by AIRcel more effectively than traditional aspiration.

4 Conclusion

The effectiveness of a biotechnological air treatment system (AIRcel) on improving air quality inside a modern and regulation compliant waste treatment facility is under investigation by the means of a fifteen months test period, during which different monitoring methods are applied in order to delineate the more comprehensive performance trial possible. The Immobilized Cell Bioreactor's system's working principle relies on motion of contaminant for concentration gradient and not through ventilation, providing a sustainable alternative to traditional air treatment techniques, both for the reduced energy consumption and lower potentially disturbing emissions. This would be a sensible improvement towards environmental, economic and social sustainability, since waste treatment facilities are widely associated with emissions of air pollutant, negatively affecting air quality in the surrounding areas
The baseline has been detected in a period of decreasing activity, up to the total stop of the plant for summer break, element which influenced application results in two ways:

1. providing a rest period for the crushing, and therefore, withdrawal of waste material, which tended to increase gaseous contaminants values due to anaerobic conditions established into the storage tanks;
2. showing a lower concentration of particulate matter due to shredder's stop, destined to be overwhelmed by working conditions,

which, actually returned concentration peaks.

The gaseous contamination has been effectively treated with an immediate response to the intensification of work and events maintenance on the system, reaching a higher value decreased by 85% compared to baseline during the last weeks.

The particulate contamination is clearly influenced by the processing conditions of the waste treatment system, both from a chronological point of view, since it is clearly recognizable the time of resumption of full operational schedule, whose concentration peaks are gradually decreasing, and topographical, since the data at the secondary shredder are higher than the one detected at the feeder section, while during the definition of the baseline (when processing of waste material has almost stopped), an opposite behavior was found.

The peaks of smell recorded inside the facility are reflected in the surveys carried out.

The smell impressions gathered by the staff and the absence of complaints from the residents around the plant confirmed a reduction of odor emissions at their source, limiting the fugitive contaminants, despite the working conditions of the venting inside the facility have not changed.

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