

Impact of a new Legislation on Volatile Organic Compounds Emissions in an Open Landfill in Tropical Insular Climate

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Abstract

Concentrations of airborne Volatile Organic Compounds (VOCs) were evaluated by monitoring landfill gases at the main municipal solid waste of Guadeloupe archipelago. Opened in 1973, the open landfill of La Gabarre is still operated nowadays. Over last decade, nature of stored waste and landfill configuration have evolved. Before 2008, waste was just spread out on the floor and there was no gas collection nor leachate recirculation systems installed. After 2009, new units were set up to collect and treat hazardous waste. VOCs measurements have been performed at La Gabarre for two distinct periods with two portable devices: an Open-Path Fourier Transform InfraRed (OP-FTIR) spectrometer in 2003 and a Mass Spectrometer (MS 200) in 2012. Four VOCs commonly found in landfill plume were measured. Between 2003 and 2012, a sharp decrease is observed in the concentrations of benzene and trichloroethylene. Tetrachloroethylene was not detected by the OP-FTIR spectrometer. Taking acetaldehyde as an example, it was hypothesized that this decrease could not be related to the difference between measurement techniques. These results suggest that in recent years with the application of a new legislation and the installation of gas collection systems, emissions of VOCs in the atmosphere due to garbage have decreased at La Gabarre.

Keywords: Landfill; Waste; VOCs; OP-FTIR; MS 200; Tropical insular climate

Introduction

Waste management has always been a major issue in island environment, particularly in an archipelagic context. Due to the strong global urbanization, waste storage always creates odor nuisance to local residents because of lack of space to collect waste [1]. Initially meant to be a temporary structure when it opened in 1973, La Gabarre site is nowadays the main open landfill of the archipelago of Guadeloupe. It is embedded in a mangrove area that surrounds it (Figure 1). The mangrove is part of the marine coastline. The Municipal Solid Waste (MSW) landfill is sandwiched between the mangrove and inhabited areas [2-4]. Just a ring road with heavy traffic separates the MSW landfill from populated areas. Regardless of the damages caused on soil and groundwater, atmospheric pollution generated by this site is substantial and potentially harmful for the on-site workers and nearby residents. Previous studies have shown that this pollution is higher during the night due to the nocturnal stable atmospheric profile and local urban heat island [2,3]. Over the years, the impact of the landfill on the flora and fauna has increased and the unpleasant smell near the site has turned unbearable. At the same time, landfill fire events have become more and more frequent. To reduce the environmental impact of the landfill, new legislation has been implemented from 2009 with the creation of specific units to store and process certain types of waste. In December 2010, rehabilitation works started in La Gabarre to collect and store leachate and biogas [4].

In landfill generated biogas, volatile organic compounds (VOCs) are the most toxic chemicals [5,6]. VOCs released from waste can have two origins. They come from anaerobic or aerobic fermentation of waste (microbiological production), or from direct volatilization of substances. The origin of VOCs depends mainly on the type of waste and on the microbiological decay stage [7]. One of the main effect of the rehabilitation is ultimately to decrease the emission of biogas compounds in the atmosphere since a network of wells dug into the waste dome lead the biogas to a flare system where it is burned [8,9]. In 2012, the wells were already dug but neither the networking of the wells nor the biogas flaring was in effect.



Figure 1: Aerial view of the open landfill (in the middle) with the mangrove and inhabited areas.

Most common analytical methods for airborne VOCs characterization involve collection and storing of the whole-air into canisters or bags or absorption of VOCs on solid sorbents following by subsequent off-site laboratory analysis such as gas chromatography/mass spectrometry [10]. However, these methods just allow to

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characterize the time-integrated atmospheric pollutants loading at a single point and do not provide spatially representative real-time temporal variations of gas levels. To address these shortcomings, many field portable devices have been developed these last years for air pollution monitoring [10]. Main advantages of these instruments are: no sample collection, handling or preparation; in situ and real time analysis; ability to simultaneously detect several compounds, etc. With two of these portable instruments, measurements have been performed in La Gabarre landfill before and after the beginning of the new organization in waste processing. In this paper are studied the results obtained with an Open-Path Fourier Transform InfraRed (OP-FTIR) spectrometer and a Mass Spectrometer (MS 200). FTIR spectrometers can detect more than one hundred COVs emitted from industrial or biogenic sources. In OP-FTIR spectrometers, the cell into which the sample will be injected is extended to open atmosphere [11,12]. Portable mass spectrometer is another interesting alternative for trace VOCs analysis. It is capable of low level VOCs monitoring and provides the advantages of laboratory mass spectrometry in the field without having to use the gas chromatography technique to separate the different chemicals in the sample [13].

The purpose of this study is twofold. First, it allows to compare the practical use of both instruments in the field, and secondly, it should assess the effect of the rehabilitation on VOCs emissions and air quality. Few studies have made use of these devices to quantify VOCs landfill emissions in tropical area. Both techniques associated with the portable feature are promising to a rapid, in situ and real time control of VOCs levels in a polluted environment, avoiding collection, transport to the laboratory and possible contamination of polluted samples. However, in both cases, in contrast with drier atmospheres, dealing with the water vapor elimination issue is a major challenge which has to be solved before any VOCs routine monitoring is operated.

Materials and Methods

Study area, meteorological conditions and field measurements

The study site is La Gabarre, an open landfill in the center of Guadeloupe archipelago ($16^{\circ}15'N$, $61^{\circ}35'W$). The landfill first started accepting waste in 1973 and is still operating nowadays. With an area of 37 hectares, this landfill is the largest of the island. The annual acceptance rate of solid waste was gradually increased from 60 000 tons per year in 1998 to 220 000 tons per year in 2008. For years, La Gabarre was used to store both hazardous and municipal waste: household waste, industrial waste, old cars, tires etc. At that time, the waste was just spread out on the floor and there was no gas nor leachate collection systems installed. For on-site workers and local residents, the health risk was obvious and increasing. In 2003; due to the lack of space on the site, piled waste was forming a small dome at the back of the landfill.

As a result of regulatory change in 2009, new units were set up to collect and process hazardous waste. In December 2010, waste dome rehabilitation works have started with the establishment of collection facilities and the treatment of biogas and leachate.

To avoid leaching of VOCs from the atmosphere, all measurements presented in this paper were performed during periods of clear sky without rainfalls. The meteorological data were collected from the airport island ground meteorological station around 3 km northeast of the landfill area.

On 03 June 2003, before the landfill rehabilitation has started, OP-FTIR measurements has been made on the waste dome during about half an hour, roughly between 9 and 9.30 am (local time). The weather was

clear due to a small rainfall event sooner in the morning, fair and sunny with light wind from the east-southeast. Data presented below are the mean concentrations calculated from the spectra collected during this experiment. At the beginning of the landfill rehabilitation, OP-FTIR equipment was no longer available and it has not been possible to assess the effect of the rehabilitation operation on VOCs levels from OP-FTIR data. It had to be waited a few years before doing new investigation of the landfill atmosphere with a mobile mass spectrometer in 2012.

The MS 200 measurement campaign was held about a year and a half after the rehabilitation has begun, from 11 to 22 June 2012, roughly from 17:30 to 18 pm, after the landfill site closure. On the week-end of June 16 and 17, no MS 200 data is available because the landfill was not accessible. The measurement campaign occurred during a very dry period associated to a Saharan dust event without any significant rainfall event. In average, the wind remained light to moderate all campaign long and mainly coming from the southeast.

In 2012, the dome of 12 ha which has reached 24 m was divided into three parts for the measurements with MS200 spectrometer (Figure 2): uncovered fresh waste (less than one month of deposit), uncovered old waste (at least 6 months of deposit) and covered waste (waste stored for more than 10 years). Measurements made at Covered waste have begun on June 15.

Fresh waste is waste newly deposited, not yet compacted and not covered (on top of the dome). At the base of the dome, old waste is part of the waste formerly deposited that has never been covered since then. Covered waste refers to waste compacted under a layer of material (tufa or topsoil, depending on the area rehabilitation achievement) and no longer visible. For this dome part, draining wells with a depth of 15 m are currently being installed to collect biogas. The shallow thirteen meters have drains which allow to bring up the biogas to the surface.

Choice of VOCs

Over 500 compounds have been identified in landfill plume [5]. Among these 500 compounds, landfill gases frequently identified in waste emanations were selected. Benzene, trichloroethylene, tetrachloroethylene and acetaldehyde have already been studied in previous studies [14,15].

Due to its high toxicity, benzene is an aromatic compound which has been extensively studied. A large volume of benzene is released to



Figure 2: This figure shows the waste dome with these three parts: fresh, old and covered waste.

the atmosphere mainly as the result of industrial processes, automobile exhaust, automobile refueling operations, but benzene is also present in tobacco smoke and plant volatiles. Due to its high volatility, once released in the atmosphere, benzene efficiently reacts with other chemicals leading to an atmospheric residence time of only a few days, and sometimes, a few hours [16]. Studies have shown that exposure to high concentrations of benzene can cause leukaemia, neurological effects, skin problems, respiratory problems etc. [17-19].

Trichloroethylene and tetrachloroethylene are often found in landfill plume [5]. To take into account the degradation of tetrachloroethylene into trichloroethylene [20], the sum trichloroethylene + tetrachloroethylene is sometimes considered [2, 21]. Trichloroethylene is mainly used for vapor degreasing and cold cleaning of metals, and as a solvent in textile industry for textile processing, dry cleaning and finishing operations [22]. Tetrachloroethylene is widely used as an industrial solvent, in textile processing, or in printing ink production [23]. It is also used for vapor degreasing in metal-cleaning operations [24]. Reaction of tetrachloroethylene and trichloroethylene with photochemically-produced hydroxyl radicals is the major mechanism of removal of both compounds. Previous works have established a tetrachloroethylene half-life of about 100 days and over, whereas trichloroethylene half-life is estimated to about 7 days [22,24-26].

For acetaldehyde, it comes from the incomplete oxidation of organic matter [7]. Acetaldehyde occurs widely in the atmosphere naturally in certain foods (bread, ripe fruits, coffee), in tobacco smoke or produced by green plants, but it is also used or produced as a chemical intermediate in many industrial processes. In the air, acetaldehyde would be degraded very rapidly through photooxidation and oxidation by the hydroxyl radicals with a half-life of about 2 to 3 hours.

For benzene, trichloroethylene, tetrachloroethylene or acetaldehyde, disposal of products containing these compounds may contribute to landfill emissions.

VOCs analysis

OP-FTIR operation: When a solid, liquid or gas sample is crossed by light, there is a radiation absorption by its molecules. Main atmospheric gases absorb in the infrared because of their molecular vibrational modes. Infrared spectroscopy give access to the absorption spectra of the sample providing that the source infrared spectrum is known. If $I_0(\lambda)$ is the intensity of the incident radiation for a given wavelength λ and $I(\lambda)$ the intensity radiation for the same wavelength after absorption by the sample's molecules, the transmission spectrum $T(\lambda)$ is the quotient from $I(\lambda)$ and $I_0(\lambda)$. $I_0(\lambda)$ is determined through the establishment of the background spectrum which is supposed to characterize the infrared light absorption without the sample.

To perform spectroscopy measurement of landfill gases in June 2003, we used a MIDAC Corporation OP-FTIR spectrometer which incorporates an IR (infrared) source, a Michelson-type interferometer and a Mercury-Cadmium-Telluride detector, attached to a Newtonian telescope [27]. All data were acquired at a spectral resolution of 0.5 cm^{-1} and signal to noise ratios were improved by co-adding up to 64 consecutive scans. All active spectra measured reflected absorption across the polluted plume sample lying in the space between the IR source and the detector. The distance between the IR source and the detector called pathlength was set to 25 m (Figure 3). It should be noted that OP-FTIR measurements are spatially integrated since the information is obtained along the entire pathlength instead of at a single point in space [12].

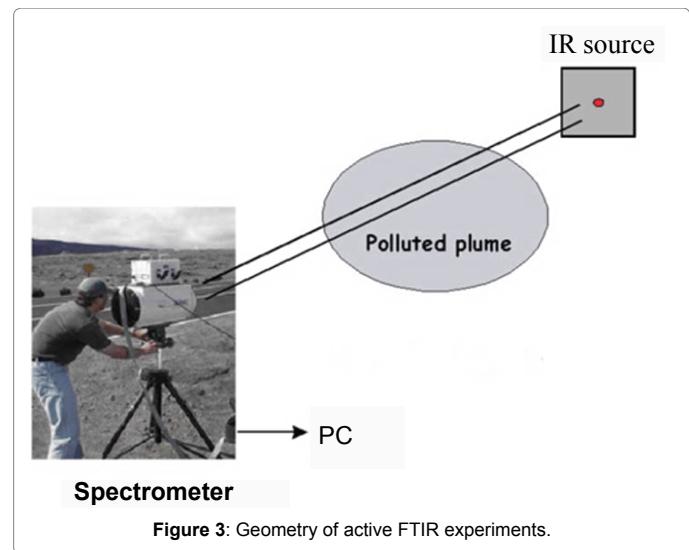


Figure 3: Geometry of active FTIR experiments.

The interferometer use makes the spectroscopy faster, since dealing with all frequencies of the polychromatic source at the same time, and results in an interferogram. The interferogram is then Fourier transformed to give the sample spectrum compared to the background spectrum in the transmission spectrum calculation. The background spectrum is either obtained from measurement through a non-polluted air, or by "cleaning" a sample spectrum. The absorbance is deduced from the transmission $T(\lambda)$ if known the pathlength and the absorption coefficient for each gas at each wavelength. This measurement technique allows to detect several compounds simultaneously [28]. It uses the absorbance properties of gases in the air in order to identify and quantify them. Instrument control, data storage, spectral analysis and concentrations calculation were performed with a notebook computer by use of the AQPRO software provided by the manufacturer.

For these OP-FTIR measurements at La Gabarre, two difficulties have to be solved: getting an applicable background spectrum and dealing with high levels of water vapor.

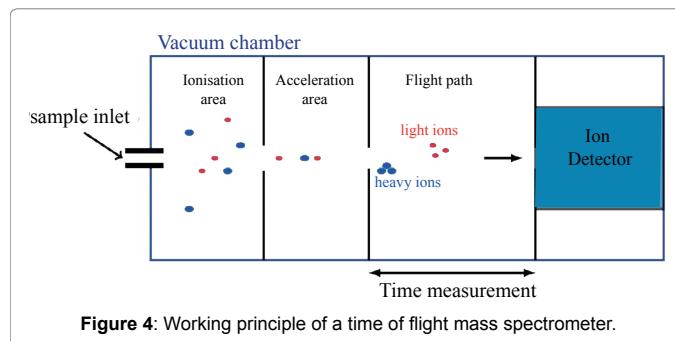
In the context of our experiments, the measurement of the background spectrum on landfill site was problematic. Traditionally, when using an OP-FTIR, the pollutant sample is supposed to be between the IR source and the detector (Figure 1). At La Gabarre, the IR source and the detector are fully immersed in the pollutant plume. The atmosphere of the area surrounding the landfill measurement site contains pollutants, although at lower concentrations. Yet, if the background used is already contaminated from the measured compounds, then the concentrations calculated for these compounds will be lower than they actually are. Measurements could have been performed elsewhere in a cleaner atmosphere, but doing this, there is a risk of undergoing experimental conditions too different, especially as regards water vapor levels. Since measuring a background spectrum in the vicinity of the landfill could not lead to accurate results, an artificial background has been reconstructed by making use of one of the measured spectra. The chosen spectrum is associated to the highest transmission levels since it is considered to be the least polluted spectrum [29].

In the classical analysis method, the ratio of each measured sample spectrum to this measured background spectrum is calculated [27]. The absorbance spectra of the pollutant gases are deduced. These absorbances are compared to a library of reference spectra of compounds supposed to be present in the site air. To have more accurate results through the

analysis, it is necessary to dispose of reference spectra recorded at the same conditions of temperature and pressure than the sample spectra and at concentrations at least greater than the concentrations expected in the sample. A calculation of their respective concentrations is made by computing what proportion of each of the reference spectra must be added to reproduce the absorbance spectrum. This method cannot be used with probing results in tropical latitudes where the water vapor is high (~85%) since the water vapor as the dioxide carbon has high absorbance peaks overlapping nearly all the VOCs infrared peaks which results in biased concentrations for such compounds. Moreover, in the regions of highest water vapor absorbance, saturation can occur which makes the detection of atmospheric gases in these spectral band impossible. An alternative method was proposed by Jock et al. [29]. Water vapor absorption is strong in 1200-2000 cm⁻¹ and 3400-4100 cm⁻¹ ranges whereas carbon dioxide absorption mainly concerns the 2200-2400 cm⁻¹ range. In order to eliminate the influence of water vapor, a background spectrum is elaborated by removing the absorbance bands due to water vapor and dioxide carbon in the measured background transmission spectrum. It is performed by manually and graphically substituting the spectrum region to be eliminated with a straight line joining its both extremities. Doing so, are also eliminated the high absorbance regions of other compounds with lower concentrations which were overlapped by water vapor and dioxide carbon. The obtained signal corresponds to an air without water vapor, dioxide carbon and VOCs. Simultaneously using this artificial background, the water vapor absorbance spectrum is introduced into the list of the gases spectra of the library. This method gives positive absorptions for calculating concentrations in the tropics. The spectral analysis ranges used in this analytical method for the four compounds investigated here are given in Table 1. To select two spectral analysis ranges for one compound allow to better discriminate compounds with similar absorption bands.

MS 200

Kore MS 200 is a portable, battery powered mass spectrometer for gas analysis entirely contained in a single case. Based on Kore's Converging Annual Time-Of-Flight (CAT) Mass Spectrometer (TOF MS), it was designed for in-situ analysis of VOCs in air [30]. The sample has to pass from the atmosphere into the vacuum chamber of the mass spectrometer. The MS 200 uses a double membrane inlet for the sample concentration. The molecules introduced into the chamber of the spectrometer are ionized by bombardment with electrons emitted by a filament. The TOF MS system measures the time a sample molecule requires to fly a given distance when charged molecules are accelerated in an electric field with a known energy. Molecular masses can be calculated by measuring the time of flight of an ion. In the ionization area, whereas the analyte is accelerated, the masses of the molecules are recorded every 20 µs. 50 000 analysis cycles are performed in an experiment of one second. Figure 4 summarizes the path of a molecule in the MS 200 chamber.



Control of the mass spectrometer and analysis of results are achieved from a laptop computer with GRAMS® software (Thermo Scientific). The MS 200 can identify many VOCs in an air sample with NIST database provided with this software.

By operating MS 200, we encountered the same difficulties as with OP-FTIR: water vapor contamination and clean background spectrum elaboration.

The MS 200 is very sensitive to atmospheric humidity. Measurements carried out in a tropical humid environment require the gas sample drying prior to analysis. In our study, it has been achieved using a Nafion dryer membrane through which water permeation occurs. In the same time, the gases we are interested in do not undergo any transformation. During our experiments, the sample line was connected to a Nafion dryer followed by the MS-200 sample inlet.

We needed a representative background of outdoor air in Guadeloupe. To perform these backgrounds, we searched for the least polluted environment possible. At "La Pointe des Châteaux" (16° 14' 58" N; 61° 11' 21" W), at the far eastern end of Guadeloupe, air masses are not yet influenced by the island anthropogenic pollution. In this location the topography is flat, vegetation cover is low and the traffic is weak except on week-ends. Several background were performed at "La Pointe des Châteaux" in order to analyze the landfill data [4].

Results

In 2003, OP-FTIR measurement have only been carried out above fresh waste. In 2012, we have evaluated VOCs emissions for different stages of waste degradation from MS 200 measurements. For fresh and old waste, the mass spectrometer was just placed on the floor near the waste pile, whereas for investigating covered waste, the device is directly connected to draining wells before any dilution in the atmosphere.

In this study, we have chosen to focus on the greatest levels of VOCs emissions reached according to each instrument. So, for both measurement campaigns, the maximum concentration measured for the four chemicals of interest is analyzed.

Tables 2 and 3 show respectively the maximum concentrations measured by OP-FTIR and MS 200 at La Gabarre.

OP-FTIR data

Table 2 presents results of the first VOCs concentrations measured at La Gabarre. For fresh waste in 2003, we have measured 750 ppb and 550 ppb for benzene and trichloroethylene and 20 ppm for acetaldehyde.

Gas	Selected spectral analysis range
Acetaldehyde	1016-1235 1cm ⁻¹ 2595-2921 1cm ⁻¹
Benzene	3003-3146 1cm ⁻¹ 668-677 1cm ⁻¹
Trichloroethylene	820-878 1cm ⁻¹
Tetrachloroethylene	886-937 1cm ⁻¹ 738-825 1cm ⁻¹

Table 1: Gas selected spectral regions in the OP-FTIR analysis method [4].

	Benzene (ppb)	Trichloroethylene (ppb)	Tetrachloroethylene (ppb)	Acetaldehyde (ppm)
FTIR	750	550	Not Detected	20

Table 2: Maximum concentration measured in 2003 with the OP-FTIR spectrometer above fresh waste.

	Benzene (ppb)	Trichloroethylene (ppb)	Tetrachloroethylene (ppb)	Acetaldehyde (ppm)
MS 200 (F)	95	4	3	12
MS 200 (O)	121	13	3	18
MS 200 (C)	340	131	14	12

Table 3: Maximum concentration measured in 2012 with the MS 200 in fresh (F), old (O) and covered (C) waste.

	Benzene (ppm)	Trichloroethylene (ppb)	Tetrachloroethylene (ppb)	Acetaldehyde (ppm)
OEL (ppm)	1	75	50	100

Table 4: Occupational Exposure Limit (OEL) value in air for the studied VOCs [32-35].

Tetrachloroethylene was never detected by OP-FTIR method. Even when measuring in other landfills or polluted sites of the archipelago, the OP-FTIR has never detected this compound [4].

MS 200 data

By analyzing Table 3, it can be seen that the maximum concentrations of almost all compounds in 2012 increase when we move from fresh to covered waste, with old waste as an intermediate step. This difference between emission levels can be explained by the stage of waste decomposition.

At fresh waste, we have measured maximum levels of 95 ppb for benzene, 4 ppb for trichloroethylene and 3 ppb for tetrachloroethylene. At covered waste, the maximum concentration is: 3.6 times higher for benzene, 32.8 times higher for trichloroethylene and 4.7 times higher for tetrachloroethylene. Between fresh and old waste the increase in the maximum concentration is significantly less than for between fresh and covered waste. For tetrachloroethylene, we note that the maximum concentration does not change for old waste. Among the three compounds, benzene, trichloroethylene and tetrachloroethylene, tetrachloroethylene which has not been detected by OP-FTIR, has the smallest concentration (just a few ppb at fresh and old waste). These lower concentrations should explain why this chemical has not been detected nine years before by OP-FTIR spectrometer. In their review of FTIR spectroscopy applications in environmental studies, previous authors have evoked the main disadvantage of OP-FTIR technique, which is to be applied only to the cases with high concentrations of gases [11].

The change in VOCs concentrations between fresh, old and covered waste shows the different steps of waste degradation. In La Gabarre, fresh waste has less than one month of deposit. This step coincides with aerobic conditions. For aerobic fermentation, VOC emissions mainly come from the volatilization of substances present in garbage. Old waste has at least 6 months of deposit. This is the end of aerobic fermentation and the beginning of anaerobic fermentation which will increase the production of VOCs. The maximum concentrations obtained at old waste are generally higher than those measured at fresh waste.

Two factors may explain why the concentrations are generally much higher at covered waste. Firstly, draining wells down to 15 meters deep in the waste dome. Consequently, these wells drain biogas of waste stored before and after 2009. Secondly, contrary to fresh waste and old waste, the main step of the production of biogas has already fully begun for covered waste. In the literature, it is said that methanogenesis can begin six months or several years after the placement of waste in landfill cells [31]. When comparing benzene and trichloroethylene values in 2003 and 2012, we can see an important decrease of the pollution related to these compounds. It is the case even when we compare concentrations at fresh waste in 2003 with the ones at covered waste

in 2012. Between both dates, the landfill rehabilitation has proceeded which could explain the improvement of emission levels. Moreover, during this period, the waste collection, sorting and recycling sectors have become better organized in the archipelago leading to a decrease of the waste amounts stored in the landfill. So, the landfill evolution does move towards the improvement of air quality as regards VOCs emissions. Unfortunately, no simultaneous OP-FTIR and MS 200 VOCs measurements could have been performed in order to calibrate the instruments to one another.

The results got for acetaldehyde which have not been yet discussed here could give a first idea of the potential measurement bias between both instruments. For acetaldehyde, we see that there is not much change in concentration levels. This is the only compound of the study for which concentration is equivalent at fresh and covered waste (12 ppm) and for which concentration at covered waste is lower than concentration at old waste (18 ppm). Unlike the other compounds, because of its formation processes, the concentration of acetaldehyde seems to be independent of the waste decomposition stage. Furthermore, the values obtained from MS 200 have the same order of magnitude as those from OP-FTIR above fresh waste (Tables 2 and 3).

Occupational exposure limit value compared to field measurements

Table 4 presents the Occupational Exposure Limit (OEL) values in air for benzene, trichloroethylene, tetrachloroethylene and acetaldehyde according to French legislation [32-35]. OEL values give the maximum level of pollutants concentration in the atmosphere, beyond which a short-term exposure poses a risk to human health. These values are measured or calculated for a reference period of eight hours with a time-weighted average.

For trichloroethylene, tetrachloroethylene and acetaldehyde, it can be noted that OEL values in Table 4 are much higher than concentration levels measured by either of both portable gas analyzers (Tables 2 and 3). At La Gabarre, these compounds have always presented a low health risk, even before the beginning of the rehabilitation.

For benzene, the gap between OEL values and measured concentrations is smaller in 2003. Difference between OEL value and OP-FTIR data (750 ppb) in 2003 for fresh waste is only 250 ppb. In 2012, MS 200 data in fresh waste indicate a benzene concentration (95 ppb) 10.5 times lower than OEL value. Looking at these results, it can be stated that the health risk related to benzene was stronger before 2009 probably due to a more usual storage of hazardous waste.

Conclusion

This original study shows the results obtained by two portable gas analyzers in tropical insular environment. Few studies have made use of these devices to quantify VOCs landfill emissions in tropical area. The results obtained exhibit an explicit trend in the evolution of VOCs emitted by waste. Between 2003 and 2012, a strong decrease in VOCs concentration emitted by fresh waste is observed. It is difficult at the end of this work to say if the differences between 2003 and 2012 values are related or not to the measurement method since the OP-FTIR and MS 200 data are not collected simultaneously

The change of nature and volume of the waste stored at La Gabarre since 2009 may be the main factor that could explain the sharp decrease in concentration of some compounds. Many hazardous wastes are no longer stored in this landfill and the upstream waste sorting and

recycling is more efficient. In fresh waste in 2012, for a carcinogenic compound like benzene, measured concentration is much lower than Short-Term Exposure Limit value. With the MS 200, it could be followed in 2012 the evolution of VOCs emissions for the different stages of fermentation (aerobic and anaerobic). Despite the difficulty associated with the water vapor processing, results are consistent with those depicted in the literature [36].

From a practical standpoint, MS 200 spectrometer has proved easier to operate and to move, faster to start, which allows to spend more time for the measurement itself and the possibility to collect several points in a same experiment. It also seems, analysing tetrachloroethylene levels, that the lower concentration are best detected with MS 200. Then, MS 200 is more suitable for investigating the lower concentration levels measured after the landfill rehabilitation. However, MS 200 data are representative of a smaller landfill area whereas the path-integrated OP-FTIR concentration takes into account all the information along the entire path length. It means that fugitive pollutant emissions can better be detected by OP-FTIR providing that the contaminated plume passes through the beam path and contamination levels are greater than OP-FTIR limit of detection values. Moreover, for each compound measured with MS 200, it is necessary to perform in laboratory a proper calibration with the help of standard reference gases, which can be expensive when a large number of gases is considered. At the opposite, the OP-FTIR spectrometer can detect and calculate all compounds providing the suitable spectra are available in the library of reference spectra. However, in both cases, in contrast with drier atmospheres, dealing with the water vapor elimination issue is a major challenge which has to be solved before any VOCs routine monitoring is operated.

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Conflicts of Interest

The authors declares that there is no conflict of interest.

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