A NOVEL TOOL FOR ESTIMATING THE ODOUR EMISSIONS OF COMPOSTING PLANTS IN AIR POLLUTION MANAGEMENT

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ABSTRACT

Odour emissions are a major environmental issue in sanitary environmental engineering plants, due to the increasing number of complaints being made by the exposed population. The particular and complex nature of the substances considered to be the cause of the odour impact, their variability in time and the climatic conditions, as well as the subjectivity of the odour perception, are the elements that have delayed their regulation. For this reason there are few international laws that set the limits of odour emissions from industrial sources and/or define the criteria of quality related to the smell. In particular, there are currently no regulations that deal with this problem in Italy.

Analytical techniques such as the use of surrogate chemical markers (i.e. H_2S or NH_3) as well as the chemical analysis of odorous mixtures by chromatographic techniques (i.e. GC-MS) can be used for continuous assessment, but are limited, due to usually being compound specific, which may not always relate to olfactory perception. Whereas olfactory assessment offers an accurate measurement of olfactory annoyance. However, the cost, potential subjectivity and time restrictions (due to being laboratory based) make them unsuitable for continuous assessment in terms of air quality monitoring.

In this study, a novel tool based on a highly innovative on-site analytical instrument (Portable GC-MS Hapsite, Inficon) was used to identify and characterize the volatile substances that cause odour annoyance and the main sources in a composting plant. At the same time, this work identified odours key compounds and investigated the relationship between their concentration measured by GC-MS analysis and the performances of the plant. The main chemical substances responsible for the olfactory annoyances were also identified. In conclusion, odour abatement system (static biofilter) efficiency was tested in terms of reduction of both key compounds and quality of the clean gas composition.

The results highlight the applicability of this tool in directly monitoring odour emissions in terms of air pollution management. 38 different substances are detected, with almost half being smell relevant components as well as responsible for the typical smell of composting plants. Limonene and 2-Butanone are identified as key compounds connected to the specific production process.

1. INTRODUCTION

Odours induced by sanitary environmental engineering plants are considered to be the main cause of annoyance noticed by the exposed population (Bertoni *et al.*, 1993; Stuetz and Frechen, 2001; Bidlingmaier, 1997; Van Harreveld, 2002; Boholt *et al.*, 1999; Lindvall, 1970; Frechen, 2003). Even though a real toxicological-sanitary risk is hardly-ever associated to the odours impact from sources connected to the activities of environmental management, due to the rarely dangerous nature of the smells as well as the generally very low concentrations, the collective imagination often associates the bad smell to conditions of "non healthy" air. In fact,

a valence higher than the one related to more dangerous contaminants, but not directly perceptible from our senses, is often attributed to them (Gostelow *et al.*, 2000; Stuetz and Frechen, 2001; Frechen, 1988; Kehoe *et al.*, 1996). Odour emissions affect the quality of life (Brennan, 1993) leading to psychological stress and symptoms such as insomnia, loss of appetite and irrational behavior (Wilson *et al.*, 1980).

Therefore, the need to monitor air quality in relation to the odour environmental levels has long been noted. However, the particular and complex nature of the substances that cause the odour impact, their variability in time as well as the climatic conditions, and the subjectivity of the odour perception are the elements that have delayed their regulation (Gostelow *et al.*, 2000; Stuetz and Frechen, 2001; Bidlingmaier, 1997; Van Harreveld, 2002).

There are few international laws that set the limits of odours emissions from industrial sources and/or define criteria of quality related to the smells. In particular, in Italy there are no regulations on smell pollution as well as objective and officially recognized methodologies for the measurement of smell levels. In European Countries, Germany is the Nation with the most specific regulations, being well defined and based exclusively on sensorial analysis (VDI-guideline, 1997; Frechen, 2003; Both, 2004). Only recently, the technical regulation EN 13725:2003 "Quality of air – measurements of smell concentration using dynamic olfactometry" has been approved in European limits, with the aim of make objective and quantifiable the intensity of an odour perceived from a group of detectors (panellists) that in a laboratory smell some samples of air at different dilutions ranges.

On the other hand, the definition of normative limits for smell emissions is a problem of hard solution for the difficulties related to the subjectivity of smell perception as well as to the ways in determining the odours in the environment. A preliminary requirement for an organic body of legislation dealing with odours, is the capacity to objectively evaluate the intensity of the subjective sensation of the odour presence.

Odour measurement is carried out using two different methods: analytical-instrumental and sensorial. It is not possible to gather the substances composing the olfactory annoyance with sensorial techniques (dynamic olfactometry, sociological questionnaires) as well as their single concentrations. It is therefore not possible to have a measurement of the number of people exposed to the different chemical agents that can cause noxious effects as well as whether they are protracted over time and in what concentrations (Stuetz and Frechen, 2001; Bidlingmaier, 1997; Van Harreveld, 2002).

The dynamic olfactometry has very high analysis costs and needs a lot of time (Sneath, 2001). The principal source of uncertainty of the olfactometric method is the biological high variability of the olfactory sensibility. Even when performed according to the EN 13725:2003, the group of panelists does not necessarily represent a statistically representative sample of the exposed population, but only a group of subjects endowed with medium olfactory sensibility. Sensorial analysis, being assigned to the "human sensor", for its own nature not reproducible, is the cause of a considerable uncertainty, due to the unavoidable human component that interferes in the evaluation (Sneath, 2001; Koster, 1985).

In this study, a novel tool based on a highly innovative on-site analytical instrument was used to identify and characterize the volatile substances that cause odour annoyance and the main odour sources in a composting plant with the aim of removing the subjective component when measuring the odours. The evaluation and characterization of the substances emitted have been studied at a full-scale composting plant. The main chemical substances responsible for the annoyances were also identified with this innovative technique. The tests are particularly focused on the efficiency of the static biofilter, used for odour abatement, because their emissions will be considered the main cause of the odorous impact on the neighbourhood and therefore contribute to the worsening of air quality (Favoino, 2002; Piccinini, 2002).

2.   MATERIAL AND METHODS
2.1 Composting Plants
The evaluation and characterization of the substances emitted have been applied to the case study of a composting plant located in Teora (AV) (Campania Region, Southern Italy). Six composting plants are now operating in the Campania Region; their localization are shown in Figure 1.
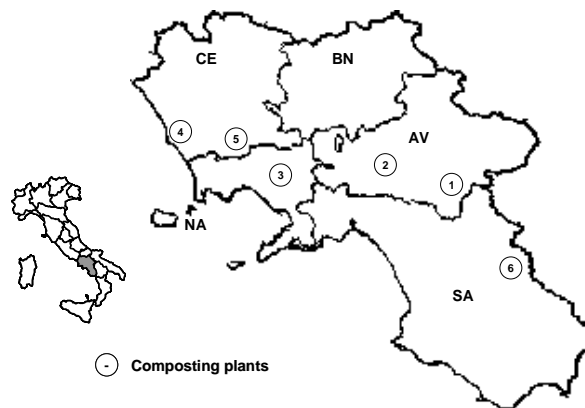
Figure 1. Localization of the composting plants in the Campania Region

The design capacity, the actual treated quantity, and input materials, in terms of SSOF (Source Separated Organic Fraction), Vegetable, and sludges from biological wastewater treatment plants, are summarized in Table 1.

Table 1. Characteristics of the operating composting plants in the Campania Region

N°	Localization	Design Capacity (t y^{-1})	Treated Quantity (t y^{-1})	Input fractions (%)		
				SSOF	Vegetables	Sludges
1	Teora (AV)	6000	2500	55	45	-
2	Avellino (AV)	1000	26	-	100	-
3	Pomigliano d'Arco (NA)	12000	3259	82	18	-
4	Castelvolturno (CE)	50000	41903	52	8	40
5	Orta di Atella (CE)	14600	2725	49	8	43
6	Polla (SA)	6000	5602	99	1	

The composting plant at Teora has a total annual capacity of 6000 t of VFG-waste (Vegetable, Fruit and Garden waste). The process takes place in underpressure sheds. Under these conditions, odours emitted by the process can be collected and treated.

The composting system was characterized by a set of 12 biocells divided in two sets of six active units respectively. The facilities developed on three plots at different heights. The total surface was about 2600 m^2. The flow chart of the main processes of the composting plant is shown in Figure 2.
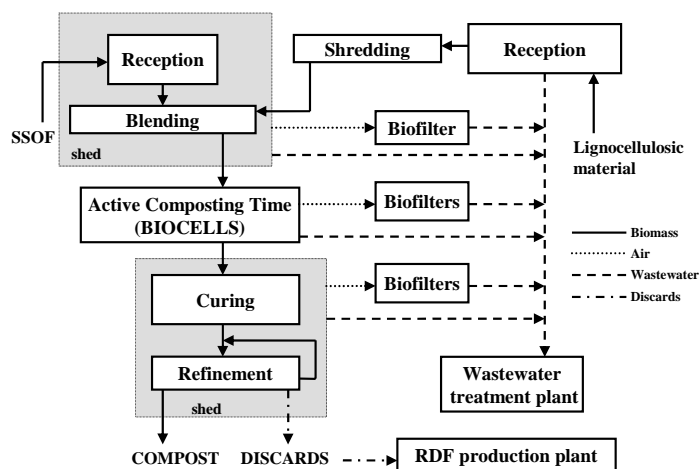

Figure 2. Flow chart of the composting plant at Teora (AV, Italy)

Odorous emissions from composting plants are essentially caused by the presence of reduced catabolic exhaust gases in the air (Favoino, 2002). In composting plants, different diffusive and non-diffusive odour sources can be identified (Zarra, 2007).

The biofilter emissions will be considered because they determine the odorous impact on the neighbourhood and contribute to the worsening of air quality (Favoino, 2002; Piccinini, 2002). Table 2 reports the main characteristics of the odour abatement systems present at the Teora plant.

Table 2. Characteristics of the odour abatement systems in Teora

Characteristics	Static Biofilter	Dynamic Biofilter
Size (m)	1,45x9,8x2,5	6,0x2,2x2,1
Filling height (m)	1,45	1,45
Contact time (s)	0,52	0,46
Gaseous affluent velocity (m s^{-1})	0,87	1,12
Load loss (mm)	16	14

2.2 Air monitoring

In this study, air samples with a portable GC-MS were analyzed in seven different points, six for the sources characterization and one outside the composting plants for the impact assessment. The analysis was carried out directly on site during the period April–May 2006.

In order to take into consideration the effects of atmospheric dispersion of the substances emitted, the measurement of the concentrations was carried out taking into account the main climatic conditions (air-wind intensity and direction, temperature, humidity, pressure).

Table 3 shows the position of the sampling points and the measurement program carried out over the testing period. 23 analyses were carried out. $P_{i,j}$ indicates the general point of analysis, with "i" referring to the location and "j" the day.

During the monitoring activities, the composting plant was managed under constant condition: input quantity of treated waste reached 40% (8 t d^{-1}) of the daily potentiality (20 t d^{-1}).

2.3 Analytical methods

Sampling and identification of the volatile compounds was carried out with a portable GC-MS Hapsite (Inficon, NY, USA). This instrument, certified by the EPA, is designed to carry out a quali-quantitative analysis of a series of compounds listed by the 1990 Clean Air Act (HAP, Hazardous Air Pollutants) directly on-site.

The qualitative analysis was used to identify the nature of the volatile substances. Under these conditions, the instrument was used with the molecular weight range set between 30-300, with a temperature program set at 40-100°C with thermal heating gradients of the gas-chromatographic column of 18 C min^{-1} and from 110-180°C with thermal gradients of 10°C min^{-1}. The sampling time of 10 seconds (Loopfill) was set and a Tenax concentrator was used. The total analysis time was 16,3 minutes.

Table 3. Sampling points and measurements program

ID	No of analyses	Location
P1	4	Wastewater treatment plant
P2	4	Shed 1 (blending) – Crude gas
P3	4	Shed 2 (curing)
P4	4	Static biofilter – Clean gas
P5	3	Biocells
P6	2	Pile of compost
P7	1	Outside the plant

Results of qualitative analyses were used to identify the key compounds. The concentration of key compounds detected was carried out through semi-quantitative analyses using a direct ratio with internal standards commercialized by Inficon (NY, USA).

Measurement of the main meteorological parameters (wind velocity, temperature, relative humidity, and pressure) was carried out using a Kestrel® 4000 Pocket Wind Meter (Nielsen-Kellerman, PA, USA) anemometer and an analogical compass to define wind direction.

Static biofilter efficiency was verified in terms of reduction of the concentration of key compounds concentration, measured of both the crude gas (P2) as well as the clean gas (P4).

3.   RESULTS AND DISCUSSION

Table 4 shows the substances detected at the sampling points of the composting plant in Teora. There are many hydrocarbons among these substances, produced by the combustion of vehicles working in the plant area. It is worth noting that exhaust air mainly contains alcohols, esters, ketones and aldehydes, as well as terpenes. Most of them are products of biological degradation, with alcohols, esters, ketones, and limonene holding the main portion (Piccinini, 2002).

In fact, of the 38 different substances detected in the mixture by the GC-MS, almost half were found to be smell relevant components as well as responsible for the typical smell of composting plants.

Terpenes occur widely in vegetation and are a major contributor to the fragrance of plants (Favoino, 2002; Piccinini, 2002). Limonene and α-pinene are often released from wood chips used as a bulking agent (Defoer *et al.*, 2002) and plant materials that are present in biowaste. Terpenes were found to be released from biowaste material during the initial stages of the composting process.

Alcohols, carbonyl compounds, esters and ethers are mainly emitted during the initial composting stage, while the volatile organic sulphur compounds, produced from anaerobic conditions in composting piles due to either incomplete or insufficient aeration, are mainly emitted during the thermophilic stage.

The most prominent substances in the analyses are considered key compounds in this kind of process. They are summarized in Table 4. They are Acetone, Limonene and 2-Butanone. Acetone was not taken into account in this study because it is not correlated to the composting process (Zarra *et al.*, 2007).

Figurs 3 and 4 plots the correlation between the presence respectively of 2-Butanone and Limonene with the other substances detected. The results show how every time that 2-Butanone is present, there is also limonene, while every time limonene is detected, there is a 67% possibility to detect 2-Butanone.

Analysis of the working parameters of the composting process not only highlight how the concentrations of 2-Butanone and Limonene are connected to the degradation of organic substances but how they are also linked to the stabilization of the compost. In fact, Figure 5 shows how the reduction of the concentration of 2-Butanone decreases as the composting process develops. In any case, the concentrations of 2-Butanone and Limonene, compared to their respective limits OT (Odour Threshold) and TLV (Threshold Limit Value), highlight how they are not responsible for olfactory annoyance, due to always being inferior. The OT and TLV of 2-Butanone was respectively set at 29 mg m^{-3} and at 147,50 mg m^{-3} (Ruth, 1986); OT of Limonene was set at 2500 µg m^{-3} while the TLV was not established.

The average concentration of 2-butanone in crude gas (P2) was 19,20 µg m^{-3}, while in the clean gas (P4) was 10,9 µg m^{-3}, with a reduction of about 50 % (Figure 5). At the same time, the substances detected on the static biofilter surface, passed from 9 compounds in the crude gas to 2 in the clean gas (Limonene and 2-Butanone).

Table 4. Organic volatile compounds measured at the emission source

| Category	Substance	P1,1	P1,2	P1,3	P1,4	P2,1	P2,2	P2,3	P2,4	P3,1	P3,2	P3,3	P3,4	P4,1	P4,2	P4,3	P4,4	P5,2	P5,3	P5,4	P6,2	P6,3	P7,4	TOT
Ketones	Acetone	x	x	x	x	x				x		x		x		x	x	x			x			**12**
	2-Butanone	x		x	x		x	x	x	x		x				x		x		x			x	**11**
	2-Eptanone	x		x																				**2**
	3-Methy-2-pentanone			x								x												**2**
	Acetophenone					x								x										**2**
	4-Methy-3-penten-2-one	x		x	x	x				x				x										**6**
Hydrocarbons	Undecane	x										x												**2**
	Methylcloride	x		x				x																**3**
	Dodecane	x																						**1**
	p-Cimene	x								x														**2**
	Decane	x										x												**2**
	1-Etil-2-methylbenzene	x								x														**2**
	1,3,5 Trimethylbenzene	x										x												**2**
	o-Xilene			x																				**1**
	p-Xilene	x		x	x					x		x	x											**6**
	1,2,4-Trimethylbenzene	x								x														**2**
	Ciclohexane	x																						**1**
	Stirene	x									x	x												**3**
	Ethylbenzene	x								x		x												**3**
	Toluene	x		x																				**2**
Terpenes	Limonene	x	x	x		x	x	x	x	x	x	x	x			x	x	x	x	x		x		**17**
	3-Carene																						x	**1**
	β-Pinene						x		x	x		x												**4**
	α-Pinene	x		x			x		x	x		x							x					**7**
Alcohols	Ethanol						x			x				x				x						**4**
	2-Ethyl-1-ethanol	x																						**1**
Volatile fat acid	Acetic acid, etinilester											x	x											**2**
	Acetic acid, 1-methyl-etilester			x																				**1**
	Acetic acid, buthyl ester	x																						**1**
	Acetic acid-2-methypropil-ester	x								x			x											**3**
	Formic acid																	x						**1**
	Acetic acid, etilester								x	x														**2**
others	Octamethyl-cyclotetrasiloxane			x																				**1**
	2-Methyl-1,3-butadiene									x														**1**
	2-Propenoic acid, 2 methyl-methyl-ester				x																			**1**
	Benzaldenyde	x						x		x		x	x	x				x						**7**
	Chloroform	x								x											x			**3**
	Tetraidro furan												x											**1**
	TOTAL	24	2	13	4	4	5	9	4	17	2	14	3	5	0	3	2	4	2	2	2	1	2	

2-Butanone [%]
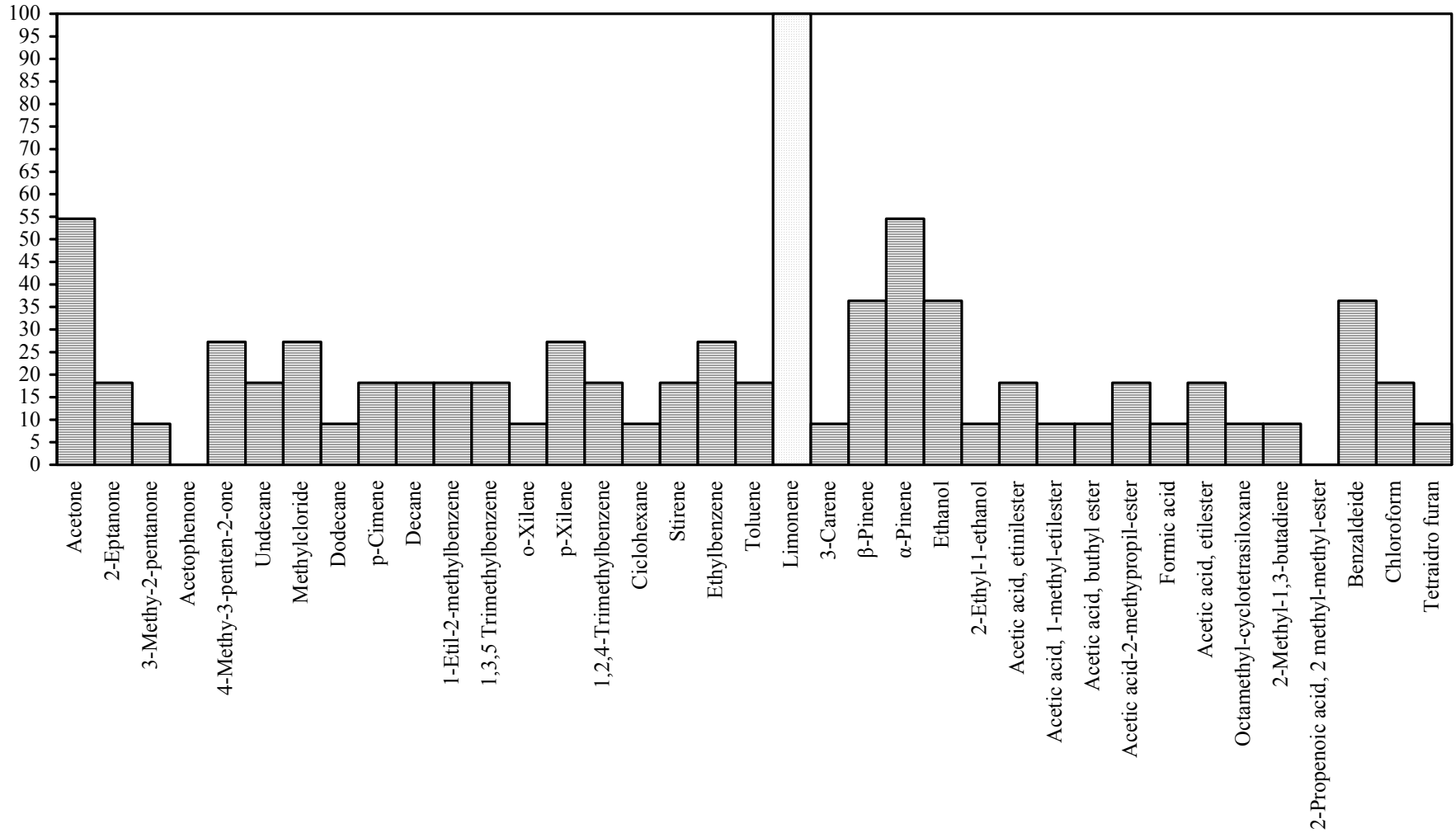
Figure 3. Correlation between the presence of 2-Butanone with the other substances detected
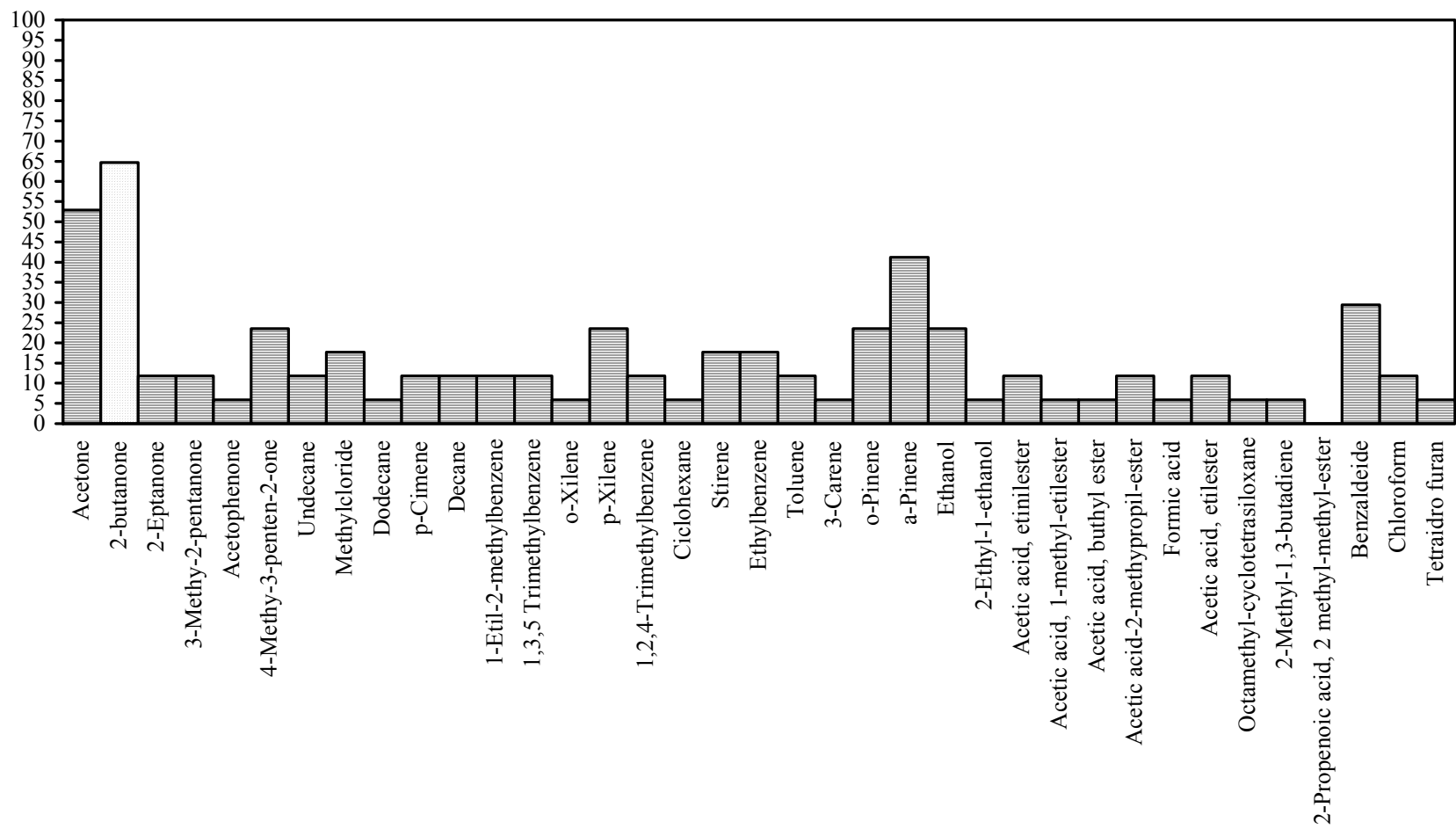
Limonene [%]

Figure 4. Correlation between the presence of Limonene (right) with the other substances detected
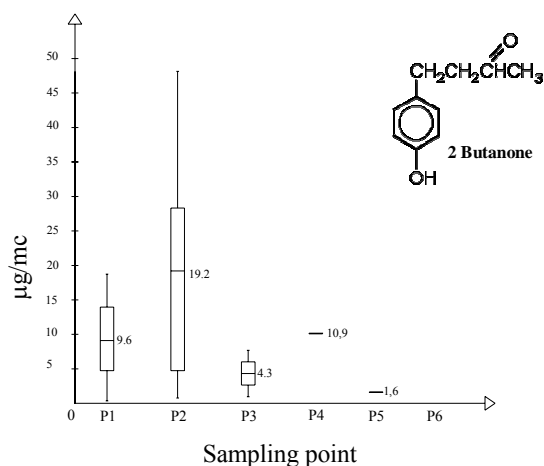
Figure 5. Concentrations of 2-Butanone detected

4. CONCLUSIONS

Odours induced by sanitary environmental engineering plants are considered to be the main cause of annoyance noticed by the exposed population.

The evaluation and characterization of the odours emissions have been applied to the case study of a composting plant located in Teora (AV) (Campania, Southern Italy). 38 different substances are detected in the process phases. Almost half were found to be smell relevant components as well as responsible for the typical smell of composting plants.

Limonene and 2-Butanone are identified as key compounds connected to the specific production process. Every time that 2-Butanone was present, limonene was also detected, while every time Limonene was detected, there is a 67% possibility to detect 2- Butanone. Moreover, the study highlights the relationship between key compound concentration and the performance of the plant. The concentration of 2-Butanone decreases as the composting process develops.

The efficiency of static biofilter was also tested in terms of key compounds and composition of clean gas.

The results highlights a new way that scientific research could be carried out in order to both identify and characterize odours impact as well as monitor the efficiency of plants.

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