ITALIAN JOURNAL OF PUBLIC HEALTH

Microbiological air quality in an urban solid waste selection plant

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Abstract

Background: Exposure to bioaerosols may pose health risks to workers operating in the processing of Urban Solid Waste (USW). The aim of this study is to evaluate microbiological air quality within an USW selection facility.

Methods: Nine sampling points in an USW selection plant situated in central-southern Italy were selected. One outdoor sampling point provided the background data. Sampling was performed on a yearly basis (2005 – 2009) upon request by the management of the selection plant. Total Mesophilic Counts (TMC), as well as fungal and Gram-negative concentrations were determined.

Results: The highest viable fungal particles concentrations (medians) were found in waste delivery areas (about 20000 CFU/m3), while the lowest were found in the control rooms (485 – 967 CFU/m3). TMC (median) was highest (6116 CFU/m3) at the delivery pit, followed by the machine shop (3147 CFU/m3), where no waste processing takes place. Medians of Gram-negative bacteria are below the suggested Occupational Exposure Limit of 1000 CFU/m3, although this limit was exceeded at several single time-points in the waste delivery areas, and also in a personnel resting room. The lowest Gram-negative contamination was found in the control rooms (medians <1 CFU/m3).

Conclusions: Some areas within a USW selection plant act as internal sources of contamination towards those areas where partially processed waste, or no waste at all, is present. Well-designed air flows, or carefully-thought positioning of areas that are not directly involved in waste processing are necessary and effective in obtaining satisfactory microbiological air quality, provided that personal protection practices are strictly enforced.

Key words: waste selection, waste recycling, bioaerosol, air quality, micro-organisms.

Introduction

Twelve years ago, Italian legislation on waste management [1,2] adopted the EC directive 91/156/CEE requiring Member States to optimise solid waste management. As a result, a steady growth in the selection and treatment of Urban Solid Waste (USW), with a 6,6 % increase in 2007 (9,5 million tons nationwide) with respect to 2006 [3], was observed. The output of waste selection plants consists, in general, of recovered materials (i.e. glass and metals), a bio-stabilized organic fraction for non-agricultural use, and combustible material for methane or energy production. Exposure to bioaerosols may cause a number of adverse effects, such as gastrointestinal, dermatologic, respiratory and allergy problems [4]. More specifically, exposure to bioaerosols deriving from waste processing [5,6] may pose health risks to workers operating in composting plants and in the collection, transport and selection of Urban Solid Waste (USW) [7-13]. Bioaerosols are composed of organic suspended materials such as live or dead bacteria, fungi, viruses, endotoxins from cell membranes of Gram-negative bacteria, antigens, toxins and mycotoxins, as well as various allergens [8]. Epidemiological studies correlating health complaints with microbiological exposure of waste collection and processing workers are scarce. However, in a recent study carried out on a group of compost workers and biowaste collectors, levels of specific IgG antibodies to molds and bacteria were measured as immunological markers of exposure to bioaerosols [14]. In that study, high exposure to bioaerosols of compost workers was shown to be significantly associated with a higher frequency of health complaints and diseases as well as higher concentrations of specific antibodies against molds and actinomycetes.

As research progresses towards risk assessment in workers exposed to bioaerosols originating from waste collection [15] and processing [16-19], existing evidence is strong enough to urge for the implementation of preventive and corrective measures to reduce exposure, such as improving facility design, replacing manual tasks with mechanical processes, wearing dedicated garments, and following individual good hygiene practices. In fact, high concentrations of airborne micro-organisms were found by Marchand et al. in 1995 in all compartments of a USW sorting, processing, and composting plant [19], and by Kiviranta at al [18] at different locations within a resource recovery plant.

This report focuses on results collected within the framework of our group's extensive experience in the environmental monitoring of waste management facilities [7,20], and of waste selection and recycling facilities [21]. Specifically, this study was carried out upon request from the management in a USW selection plant located in central-southern Italy in close proximity to a landfill.The facility adopts a number of preventive measures in terms of plant and process design, and individual protection and practices. These should positively impact workers exposure to bioaerosols, as well as to other hazards (physical and ergonomic) that are not dealt with in this paper.The aim of this study is the microbiological monitoring of air in the areas that are likely to act as contamination sources within the facility, and to assess the efficacy of facility design and management in preserving the air quality of those working areas where contamination may spread, so as to minimise health risks for personnel.

Methods

The selection plant, situated in central-southern Italy, is located in close proximity to a landfill. It is capable of processing up to 1200 tons/day, and employs a total of 12 personnel units, distributed over shifts ensuring the presence of eight units at a time (Table 1). The waste selection process encompasses five steps: a) USW dropping from trucks into a delivery pit in a closed building. Waste dropping occurs at a gate separating the building from the outdoor area. b) Loading of the waste into an automated bag shredder, feeding two automated selection lines. This is accomplished by means of remotely-operated cranes equipped with orange-peel buckets. c) Automated selection of three fractions: a non-recyclable "dry fraction" to be subsequently pressed (up to 100 tons/h); a raw "wet fraction", composed of organic material; metals (iron and aluminum) for recycling. d) Aerobic digestion of the raw wet fraction to obtain stabilised organic material. e) Further refinement of the stabilised organic material: elimination of non-organic materials such as glass or stone fragments.

All of the five steps are carried out within a single building in which the following operational areas are defined: waste dropping gate, delivery

Table 1. Workers presence at different operational areas in the waste selection and processing plant.

Location	Personnel	Time (hrs) / working day
Delivery pit	1	≤ 5
Machine shop		As required (<30 min)
Gen. ctrl room	2	6
Pressing area	1	6
Crane ctrl cabin	1	6
Compost. Plant	1	Periodical inspections (<1 hr each)
Compost refining	1	Periodical inspections (<1 hr each)
Waste dropping gate	1	≤ 3,5
Resting room	-	-

pit, crane control cabin, general control room, dry fraction pressing area, machine shop, composting plant, and compost refining area. A resting room for personnel is also present in the building, and, even though it does not qualify as an operational area, it is considered part of the facility and is, therefore, included in this study. The building is kept at an overall slightly lower pressure with respect to the outdoors in order to confine contaminated air, and convey it to biofiltration through beds of organic matter activated with selected bacteria. An air conditioning plant draws fresh air into the general control room and into the crane control room, so that a slight excess pressure prevents intake from the waste processing areas.

Table 1 summarises workers' presence during a regular working day in the different areas of the facility. Workers are operating continuously at the waste delivery pit, the crane control cabin, the general control room, and the dry fraction pressing area. The machinery in the composting plant and in the compost refining area is periodically inspected by personnel during the working day. Personnel are only present as required in the machine shop for short periods of time. Sampling was performed on a yearly basis on request from the management of the selection plant, starting May 2005 to February 2009. During this period of time, five campaigns of air sampling were performed during regular working days. Unfortunately, access to the facility could not be planned in such a way as to follow a seasonal schedule. Nine sampling points were selected, based on the type of activity and operators presence, and sampling was performed only in fully operational areas. One additional outdoor sampling point was established at about 100 m so as to provide background data of the area where the selection facility is located.

Quantitative analysis

In order to assess the level of environmental contamination by culturable bacteria and fungi, air sampling was performed using orthogonal impact sampler Surface Air System (SAS) Super 180 (PBI International) positioned at about 1,5 m height. SAS Super 180 conveys a predetermined volume of air with a constant flow rate of 180 litres per minute onto the surface of Rodac Contact Plates (Oxoid) with suitable culture medium on which the microbial cells carried in the bioaerosol adhere. Suitable volumes for a reliable count of culturable micro-organisms were optimised, for each parameter, prior to the beginning of the study by sampling different volumes (10 to 240 L), based on the expected contamination level of each area. Culture media and air volumes were established as follows: Standard Plate Count Agar (Oxoid), 30-120 L for Total Mesophilic Count (TMC); MacConkey (Oxoid), 60-240 L for Gram-negative bacteria; Sabouraud Dextrose Agar (Oxoid), 10-60 L for fungi. Incubation conditions were 24-48 hrs at 37±1°C for TMC and Gram-negative bacteria, and at 25±1°C for 72 hrs-5 days for fungi. The grown colonies were counted, specific statistical corrections were made using correction factors obtained for each growing medium from Conversion Tables (PBI reference guide) for SAS 180. Sampling was performed in duplicate at each time-point and at each location. Temperature and relative humidity were measured during each sampling by means of a psicrometer.

Data entry and statistical analysis

Results were entered into a database (MySQL 5.0) using custom-made data entry software that is specifically designed to ensure data quality through "double data entry".

For statistical analysis, data subsets were extracted and imported into Epi Info 3.5. Results of TMC, Gram-negative bacteria, and fungi are presented as means for each year, and medians and ranges are calculated for each location. The statistical significance of differences between median values of each location was tested using the Kruskal-Wallis test. Statistical significance was set at $P<0,05$.

Table 2. ECA 12 categories of CFU/m³ (mixed populations of bacteria or fungi) obtained with the Andersen six-stage sampler in indoor non-industrial and non-domestic environments [22].

	Mesophilic Bacteria (CFU/m³)	Fungi (CFU/m³)
Very low	< 50	< 25
Low	< 100	< 100
Intermediate	< 500	< 500
High	< 2000	< 2000

Data evaluation

Median values of CFU/ m^3 for each sampling location are compared with the categories defined by European Collaborative Action Report No. 12 (ECA 12) [22] for non-industrial indoor environments (Table 2).

Results

When discussing data of viable fungal particles and bacteria from air sampling, and attempting comparisons between the results of different studies, one should always keep in mind that the results obtained are strongly dependent on the cut-off point of the device used, and on the sampling time and volume [23,24]. This is one reason why reference values and Threshold Limit Values for microbiological indoor contamination are difficult to establish. In fact, no definitive acceptable exposure levels have been defined that would allow for a correct evaluation of health impact of an indoor environment. Nevertheless, there have been several attempts at defining categories (Table 2), and providing guidelines for indoor microbiological contamination based on ranges of CFU/m^3 of fungi and bacteria [22,25,26]. These are based on observed values in different environments, and they do not constitute a health risk evaluation.

The microbiological data in the present study (Table 3) show some variability in the results between sampling campaigns, especially in terms of bacterial concentrations. Since sampling was performed upon request from the plant management on a yearly basis, it was not possible to plan sampling campaigns in all seasons. As a consequence, the range of temperatures (22-26°C) and relative humidity values (40-60%) was too narrow to attempt any correlation between microclimatic conditions and differences in microbiological data among sampling campaigns. Other factors that may have resulted in data variability between sampling campaigns at each location could be the amount and quality of the waste being treated at the time of sampling, and/or the effect of local turbulence during sampling. Further investigation would be needed to test these hypotheses. Therefore, data discussion only focuses on the median of CFU/m^3 (either bacterial or fungal) for each sampling point.

Given the type of activity carried out in the plant, some level of contamination is expected. Marchand et al. [19] reported airborne total bacterial counts as high as 75,500 CFU/m^3 , and fungal counts of 7,200 CFU/m^3 at the garbage storage location within a Municipal Solid Waste recycling and composting plant. Kiviranta at al. [18] detected 150,000 bacterial CFU/m^3 and 112,000 fungal CFU/m^3 in the waste processing room of a resource recovery plant. One approach to the evaluation of proper facility and personnel management in terms of microbiological air quality optimization can be to distinguish areas that act as internal contamination sources (i.e. where waste is directly processed), from those that are accessory to waste processing. The aims of any preventive or corrective measure taken in the facility design and management should, then, be to: i) minimise spreading of microbiological contamination from areas that constitute internal sources towards other areas within the plant; ii) minimise health risks for personnel working in contaminated areas.

In the plant under investigation in the present study, the areas that can be defined as internal contamination sources, i.e. where waste is present or processed, are the waste dropping gate, the delivery pit, the pressing area, the composting plant, and the compost refining area. The areas that are accessory to waste processing are the control rooms, the machine shop, and the resting room. Results in Table 3 show statistically significant differences in air quality, depending on the activity carried out in the specific areas, and on their structural characteristics, such as position within the facility, and presence of air conditioning.

The highest fungal contamination was found at the waste dropping gate and in the delivery pit (medians of 19100 and 22645 CFU/m^3 respectively), where raw, fresh waste is first discharged from the trucks, then transferred to the selection lines. These operations are likely to cause spreading of light, non-adhesive fungal particles in the air. In fact, fungal concentrations exceed the ECA 12 "high contamination" level (Table 2) by a factor of ten. Compared to fungal, bacterial contamination at the waste dropping gate (median of 1034 CFU/m^3 TMC) was lower, with single values (Table 3) falling into the intermediate to high contamination levels according to ECA 12, with the exception of the 2008 sampling (5258 CFU/m^3). This difference between fungal and bacterial contamination levels can be attributed to the easier airborne spreading of fungi compared to bacteria, which are more strongly adherent to fresh bulk waste. On the other hand, the TMC at the delivery pit (median of 6116 CFU/m^3) was higher than that at the gate. In fact, while waste dropping occurs at the interface between the outdoors and the building (which is slightly depressurised), so that

Table 3. Microbiological data from air sampling (mean values from N=2, medians and ranges) and P values from the Kruskal-Wallis test.

Location	Year	TMC (CFU/m³)						Gram-negatives (CFU/m³)						Fungi (CFU/m³)					
		2005	2006	2007	2008	2009	Median [Range]	2005	2006	2007	2008	2009	Median [Range]	2005	2006	2007	2008	2009	Median [Range]
Delivery pit		4683	1683	14800	13200	6033	**6116** [1669-16428]	4789	130	600	3850	550	**688** [116-5854]	3617	21900	20000	27600	32100	**22645** [3025-33596]
Machine shop		4116	2733	7400	3250	1217	**3147** [1083-8214]	155	125	1530	317	317	**284** [109-1784]	1383	5400	7400	21900	5000	**5688** [1308-27036]
Gen. ctrl room		200	150	2925	433	166	**210** [129-3247]	<1	<1	97	50	<1	**<1** [0-112]	516	180	2163	1889	967	**967** [146-2581]
Press.		2249	568	n.d.	n.d	1000	**1000** [520-2812]	377	8	n.d	n.d	255	**255** [6-433]	2717	4800	n.d.	n.d.	9733	**4800** [2345-11795]
Crane ctrl cabin		50	8	38	967	33	**39** [6-1074]	<1	<1	17	13	<1	**<1** [0-18]	633	570	33	3467	167	**485** [27-3641]
Compost. Plant		299	241	2434	3142	567	**567** [206-2488]	183	21	371	150	58	**150** [19-399]	2083	66	767	9234	6933	**2083** [50-9866]
Compost refining		249	1117	6234	13734	433	**1117** [216-15245]	11	<1	178	133	<1	**11** [0-188]	3749	100	2900	7300	3600	**3331** [93-7581]
Waste dropping gate		1226	688	863	5258	1249	**1034** [601-5837]	316	346	63	4475	312	**316** [60-4964]	1683	19100	9400	28800	71100	**19100** [1580-83770]
Resting room		958	46	100	3460	121	**123** [43-3841]	205	238	26	4663	237	**233** [23-4740]	1050	66	767	7334	433	**767** [52-9122]
Outdoors		n.d.	n.d.	n.d.	242	125	**177** [111-269]	n.d.	n.d.	n.d.	<1	4	**1** [0-5]	n.d.	n.d.	n.d.	3993	3600	**3966** [2809-4444]
P							**<0,0001**						**<0,0001**						**<0,0001**

n.d.= not determined

fresh air is drawn through the gate, the delivery pit is an actual indoor environment where waste is temporarily stored, therefore constituting one of the potential contamination sources within the facility.

Microbiological contamination at the gate and delivery areas had a comparatively low impact on adjacent areas where there is air conditioning (i.e. both control rooms), and correct air flow direction has been established. In fact, in the air conditioned general control room and crane control cabin, bacterial (medians of 210 and 39 CFU/m^3 respectively) and fungal (medians of 967 and 485 CFU/m^3) contamination levels were at least one order of magnitude lower than in the adjacent delivery pit. The data from these areas compare favourably with those reported by Kiviranta et al. [18] for the control room of a resource recovery plant (7800 bacterial CFU/m^3 and 3300 fungal CFU/m^3). On the other hand, quite high microbiological contamination was found in the machine shop (medians of 3147 CFU/m^3 TMC and 5688 CFU/m^3 fungal), which is adjacent to the delivery pit, and where no air flow control has been implemented. In fact, bacterial and fungal medians in the machine shop parallel those of the delivery pit, although numerical values are lower.

A similar situation was found at the pressing area. No air flow control or air buffer has been established between the delivery pit and the pressing area, resulting in high to very high contamination levels being measured (medians of 1000 CFU/m^3 TMC and 4800 CFU/m^3 fungal), even though in the pressing area, dry waste is processed, which is less likely to be a source of microbiological contamination. In fact, numerical values were somewhat lower than in the delivery pit.

Microbiological air quality at the composting plant (medians of 567 CFU/m^3 TMC and 2083 CFU/m^3 fungal) was better in comparison to areas where unprocessed waste is temporarily stored, transferred or processed. In fact, the composting process involves slow turning and displacement of the organic material while maintaining good air flow, so that dispersion of dust is minimised [8]. Compost refining, on the other hand, involves fast transfer and tumbling of the organic material, which is more likely to create a dusty environment. However, the organic material is already stabilised, so that contamination is relatively limited in terms of airborne Gram-negative bacteria (median 11 cfu/m^3, vs. 1117 median CFU/m^3 TMC) and viable fungal particles (3600 CFU/m^3).

The resting room produced interesting data, in that TMC, Gram-negative bacteria, and fungi are comparatively low (medians of 123, 233, and 767 CFU/m^3 respectively), given the vicinity to the processing plant. However, at one single time-point in 2008, all values were high with respect to all others at the same sampling site (3460, 4663, and 7334 CFU/m^3, respectively). In fact, the 2008 sampling was carried out while workers were entering the room for a break between shifts. This result stresses out in a quantitative fashion the importance of strict enforcement of rules on working garments and individual hygiene practices.

The highest concentration of Gram-negative bacteria was found in the delivery pit, machine shop, waste dropping gate, and the staff resting room with medians of 688, 284, 316 and 233 CFU/m^3 respectively. These values do not exceed the suggested Occupational Exposure Limit of 1000 CFU/m^3 [17]. However, this limit is largely exceeded at single time-points in the waste delivery areas, and in the resting room. Again, the lowest contamination levels for Gram-negative bacteria were found in the general control room and crane control cabin (medians <1 CFU/m^3).

Discussion

The results presented in this paper support the distinction between areas, within an USW selection plant, that act as contamination sources, from those that, being accessory to contaminating activities, should be preserved from spreading of bioaerosols. Among the former, some areas should be regarded as "heavy" microbiological contamination sources, since both bacterial and fungal concentrations are high due to the presence and processing of raw waste, while other areas, such as the dry waste pressing area, may only be "mild" contamination sources, and should be preserved from second hand contamination from the "heavy" areas. In other areas, such as those dedicated to composting, air contamination by living organisms may not be the most critical problem to assess, as will be illustrated below.

Based on microbiological results, this study confirms that a correct management of air flows within an industrial building where sources of bioaerosols are present can result in a good control of air quality in selected areas of the facility. However, some areas require a higher attention level in terms of workers protection. These are the waste dropping gate, where truck drivers are present during waste downloading, and the delivery pit, where personnel are required

when larger-sized materials, not suited for the selection lines, need to be removed. In these areas, individual protection practices should be strictly enforced as a precautionary measure, as required by EC and Italian law [27].

Air flow control should be implemented at the pressing area, where personnel are present throughout the entire work shift, in order to prevent the intake of bioaerosols from sources of heavy contamination.

The machine shop, as described above, exhibits high microbiological contamination, however permanence of personnel is not continuous and can be variable since it depends on the specific task to be carried out. Given the nature of this area, which is not dedicated to waste handling and processing, corrective measures should be taken in order to achieve better air quality. Specifically, the implementation of an air flow system that prevents contamination from areas where raw waste is handled should be undertaken. As an alternative, a repositioning of such accessory room may be sufficient to ensure satisfactory air quality. In fact, one can observe that the resting room, which is removed from the waste processing areas, exhibits good (bacteria) to intermediate (fungi) microbiological air quality. This observation does not hold true at one single time-point (i.e. in 2008), but this may be due to unusual crowding by workers coming directly from the operational areas of the waste processing plant, rather than to the position or structure of the resting room. In fact, as a result of the high values found in 2008, it was suggested to the management to emphasise correct clothing policies with personnel when moving from one area to another. This seems to have positively impacted microbiological air quality in the resting room, as shown in the 2009 results.

Gram-negative bacteria exhibit comparatively high values, relative to TMC concentrations; however, the medians observed do not exceed the suggested Occupational Exposure Limit of 1000 CFU/m^3 [17].

The present study can be considered as a starting point for the improved assessment of overall air quality in a waste management plant. In fact, a better characterization of the internal contamination sources should be achieved through repeated sampling at different times during the working day. Furthermore, one should take into account the specific task being carried out during sampling in each area, in order to obtain homogeneous data. For example, sampling should be performed at the delivery pit during waste discharge from the trucks, during transfer by buckets into the selection lines, or at rest. Seasonal differences should be verified through sampling in different climatic conditions. Furthermore, in view of a more comprehensive assessment of air quality in all areas of the building, one should consider that monitoring of live micro-organisms concentrations is only part of the problem, particularly in the composting plant, since adverse health effects or complaints may arise from exposure to other substances of microbiological origin, that cannot be evaluated based solely on micro-organisms counts. These include bacterial toxins, micotoxins, 1,3-β-D-glucans fungal spores, and waste-derived Volatile Organic Compounds (VOCs), including odorous substances [28], alcohols, furanes, and terpenes. In fact, besides the well-known adverse effects of bacterial and fungal toxins, such as fever, respiratory and gastrointestinal problems [8] caused by endotoxins produced by Gram-negative bacteria, Molhave et al. [29] have shown that even low concentrations of VOCs can cause irritation of the eyes, nose, and throat in workers at waste handling plants. A qualitative investigation carried out by this laboratory [30] confirmed the presence of bacterial endotoxins at the waste delivery pit within the plant discussed in this paper. In short, in order to establish the critical microbiological and chemical parameters of interest in view of health risk assessment, a more comprehensive study needs to be undertaken, in which microbiological data, airborne toxins concentrations, and VOCs concentrations in the working environment are determined in a systematic and quantitative fashion.

Acknowledgements

We wish to thank Roberto Favara for his technical support, and Alice Mannocci and Claudio Bontempi for useful discussion on statistical analysis of the data.

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