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DETERMINING THE CHARACTERISTICS TO BE CONSIDERED FROM A WORKER HEALTH AND SAFETY STANDPOINT IN HOUSEHOLD WASTE SORTING AND COMPOSTING PLANTS*

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Abstract: This report presents the results of a study of chemical and biological contaminants and ergonomic hazards in two (A and B) household waste treatment centers (the only ones in the province). The goals of this study were to document the nuisances (chemical and biological) in a composting and sorting plant, and to interpret these data by comparing them to the standards and recommendations reported in the scientific and technical literature. Microbial samples of air were collected using the methodology recommended by the ASTM (American Society for Testing and Materials) in their protocol E 884-82. Chemical contaminants were measured using the IRSST's standard methods. In the reception areas of centers A and B, and in the fermentation buildings, the total bacteria concentrations were higher than the maximum suggested level of 10,000 colonies per cubic meter of air (cfu/m^3) set for this type of activity. When the concentrations of Gram-negative bacteria are compared to the maximum level of 1,000 cfu/m^3 of air, no sampling station exceeded this value. The maximum concentration of thermophilic actinomycetes (15,000 ±150 cfu/m^3 of air) was found in center B's fermentation building. Concentrations of *Aspergillus fumigatus* were significantly higher ($p \leq 0.05$) than in the outdoor air in all workstations of plant B's and in plant A's fermentation building. Total mold concentrations were significantly higher ($p \leq 0.05$) than in the outdoor air at center A's reception area, and in both centers' fermentation buildings. The concentrations of chemical contaminants in center B's fermentation building were 50% less than the regulated exposure value, and higher than this 50% of the regulated exposure value for ammonia, carbon dioxide and hydrogen sulfide in center A. Finally, the quality of the outdoor air, 100 meters downwind, does not seem to be affected by the operations performed in these centers.

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INTRODUCTION

This report presents the results of a study of chemical and biological contaminants and ergonomic hazards in two sorting and composting centers in the province of Quebec. In fact, since this type of workplace is new and relatively unknown, it is important to pursue research on the evaluation of the aggressors, mainly those of a chemical, biological and ergonomic nature [11]. The data collected can be useful in developing not only knowledge about these workplaces but also health programs adapted to the risks to which workers are exposed.

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The goals of this project are:

a) to document the nuisances (chemical, biological and ergonomic) in sorting and composting centers, and

b) to interpret these data by referring to the standards and recommendations reported in the scientific and technical literature.

According to the literature consulted, waste sorting and composting has risks of a chemical, physical, microbiological and ergonomic nature as well as risks to worker safety [18, 24]. Sorting may be one of the processes most likely to expose workers to high concentrations of Gram-negative bacteria [18, 21, 24]. The endotoxins released by these bacteria can produce symptoms ranging from irritation of the mucous membranes to gastrointestinal and respiratory problems [2, 4, 5, 14, 21, 22, 25, 33, 34]. In fact, according to a Danish report, several studies have indicated that workers in recycling and sorting plants are exposed to increased risk of musculoskeletal and respiratory problems (bronchitis, chest congestion, etc.), organic dust toxic syndrome (ODTS), gastrointestinal problems, and skin, mucous membrane and eye irritation [36, 37]. Other types of microorganisms can also cause infectious illness or have toxic effects by entering the respiratory system [21, 24]. These microorganisms include thermophilic actinomycetes, due to the temperatures reached by the compost, and thermoresistant molds such as *Aspergillus fumigatus* [4, 21, 22, 24]. Lauwerys [16] mentions that the handling of compost in mushroom production companies may cause extrinsic allergic alveolitis (bagassosis, farmer's lung). *Aspergillus fumigatus*, which is sometimes pathogenic, may cause lung infections in immunodeficient individuals as well as aggravate the symptoms in asthmatics [2, 16, 26, 27, 33].

The literature on sorting-composting centers reports concentrations of total bacteria above 20,000 colonies per cubic metre of air (cfu/m^3), concentrations of Gram-negative bacteria above 6,000 cfu/m^3 of air, concentrations of molds above 10,000 cfu/m^3 of air, and concentrations of endotoxins varying from 480 to 990 ng/m^3 of air [24, 25, 31, 36]. These values are of the same order of magnitude as those found in a Quebec sorting-composting center during an IRSST study [18].

There are no Quebec or international standards on microorganisms and their toxins. However, based on earlier studies on wastewater treatment and on composting plants, the following guidelines have been proposed [24, 25, 31]:

- Total bacteria: 10^4 cfu/m^3 of air.
- Gram-negative bacteria: 10^3 cfu/m^3 of air.

The chemical contaminants involved in composting are nitrogen compounds (NO_x, N_2O, NH_3), carbon dioxide (CO_2), and if anaerobic conditions are present, hydrogen sulfide (H_2S) [11, 21, 24, 30]. In waste handling, the chemical substances that the workers could come in contact with, either through inhalation or through skin contact, essentially depend on the nature of the waste.

MATERIALS AND METHODS

The population served by center A is approximately 50,000 people. The waste is first sorted by the citizens. To begin, the waste is dumped into a pit inside the plant. The fermentation cylinder (bioreactor) where composting takes place is continuously fed from this pit. At the bioreactor outlet, the compost is refined by mechanical sorting, and the recyclable material recovered by manual sorting. The compost is placed in windrows in the fermentation building and turned until it matures. The capacity of this system is 42×10^6 kilograms per year. The plant operates twelve hours per day, seven days per week, and employs twelve people in operations and maintenance. The description of center B is the following: the composting operation consists of pretreatment (shredding of waste and sorting with a trommel screen), and then the actual composting. The waste is placed in windrows with a wheel loader. Subsequently, the waste is transported to a curing zone outside. Eventually there is another sorting with a trommel screen. The trommel screen waste is incinerated. Note that there are no bioreactors. Household waste is sorted by the citizens. The amount of waste treated is 145,000 kilograms per week during the summer, and between 68,000 and 90,700 kilograms during the winter.

The concentrations of microorganisms measured during a preliminary study have shown that more than five samplings is enough to demonstrate statistically significant differences with the recommended levels ($p \leq 0.05$) [7, 38]. This number of samplings agrees with that recommended by the ASTM (American Society for Testing and Materials) in their protocol E 884-82 [3]. The microorganisms in the air were sampled using Andersen impactors (Andersen Instruments Incorporated, Atlanta, USA), as recommended by the ASTM [3]. The total coefficient of variation for this method is 0.23 for waste treatment plants [20].

The microbiological contaminants measured in the air and the culture media used were the following:

- SDA (Sabouraud dextrose agar, Quelab Laboratories, Montreal, QC, Canada). Total mold samples were incubated for seven days at ambient temperature. *Aspergillus fumigatus* samples were incubated for seven days at 45°C.
- TSA (Trypticase soya agar, Quelab Laboratories, Montreal, QC, Canada). Total bacteria samples were incubated for 48 hours at 35°C. Thermophilic actinomycetes (thermoactinomycetes) samples were incubated for 48 hours at 55°C.
- MacConkey medium (Quelab Laboratories, Montreal, QC, Canada). Gram-negative bacteria were incubated for 48 hours at 37.5°C.

The samples were collected at each of the workstations or sections of the plant, as recommended in the ASTM protocol [3]. In center A, there are nine workstations, including the outdoor air which is used for comparison during the summer only. In center B, there are five. The

Table 1. Average concentrations of biological contaminants (±standard deviation) in center A.

Contaminant			Total bacteria		Gram neg.		Thermoactino.		*A. fumigatus*		Molds
Guidelines*			10,000		1,000		-		-		-
		n	cfu/m^3	n	cfu/m^3	n	cfu/m^3	n	cfu/m^3	n	cfu/m^3
Upwind	Summer	6	2,300 (1,150)	6	12 (18)	6	N.d.	6	20 (1)	3	6 (14)
	Winter	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.
Downwind	Summer	6	5,490[a] (2,550)	6	N.d.	6	6 (14)	6	6 (14)	5	1,100 (90)
	Winter	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.
Air intake	Summer	6	6,970[a] (2,325)	6	12 (18)	5	60[a] (20)	6	11 (18)	6	1,190 (180)
	Winter	5	4,400 (1,590)	6	110 (100)	6	12 (30)	6	25 (40)	6	50 (80)
Control room	Summer	6	4,750[a] (660)	6	N.d.	4	730[a] (300)	6	1,040[a] (270)	2	2,230[a] (580)
	Winter	5	2,840 (1,740)	6	N.d.	4	210[a] (120)	5	170[a] (110)	2	2,910[a] (330)
Bioreact. out	Summer	6	2,210 (540)	6	N.d.	5	160[a] (140)	5	55[a] (30)	6	1,650 (810)
	Winter	4	3,360 (970)	6	N.d.	5	50[a] (30)	5	560[a] (560)	5	1,800[a] (250)
Sorting	Summer	6	3,940 (1,650)	6	18 (19)	3	150[a] (55)	6	N.d.	4	60 (20)
	Winter	6	1,925 (1,025)	6	150 (10)	5	90 (90)	5	620[a] (420)	6	1,020[a] (280)
Bioreactor	Summer	6	4,715 (2,585)	5	N.d.	3	700[a] (230)	4	70[a] (30)	4	1,120 (150)
	Winter	6	2,560 (820)	6	N.d.	5	90[a] (40)	6	100[a] (60)	5	560[a] (130)
Reception	Summer	6	53,690[a] (16,000)	3	310[a] (80)	4	2,330[a] (710)	5	N.d.	4	13,670[a] (425)
	Winter	4	68,920[a] (20,340)	6	510[a](110)	5	340[a] (270)	5	630[a] (420)	6	14,380[a] (730)
Fermentation	Summer	6	168,440[a] (2,270)	2	70[a] (45)	4	2,790[a] (1760)	6	Invasion	4	13,670[a](425)
	Winter	5	5,090 (1,590)	6	N.d.	5	4,610[a] (910)	5	12,000[a] (2,900)	6	10,180[a](1,130)

[a]Average concentrations significantly greater ($p \leq 0.05$, Student t-test) than those in the upwind outdoor air; N.m.: Not measured; N.d.: Not detected; *Recommended guidelines [24, 25, 31].

ASTM recommends collecting these outdoor samples 300 metres upwind from the plant and 100 metres downwind [3].

The chemical contaminants were measured in the compost fermentation area at the same time as the biological contaminants, at a height of 1.5 m, continuously for one day, with direct-reading monitors connected to a data collection module (Model DLX-100, D.E.S. Corporation, Quebec, QC, Canada). It should be noted that these measurements covered the windrow turning period. The procedures took place in summer, when the amount of waste is at maximum, and during winter, under different ventilation conditions. N_2O, NH_3, CO_2 and CO were measured with a multi-gas photoacoustic spectroscopic monitor (Model 1302, Brüel and Kjaer, Pointe-Claire, QC, Canada) with a detection limit of 0.025 ppm for N_2O, 0.3 ppm for NH_3, 3 ppm for CO_2, and 0.15 ppm for CO. Hydrogen sulfide was measured with an electrochemical monitor (Model 4173, Interscan Corp., Chatsworth, CA) with a detection limit of 0.4 ppm. NO and NO_2 were measured with personal electrochemical monitors (Toxilog, Biosystems Inc., Middlefield, CT). Detection limits are 0.1 ppm for NO_2 and 1.0 ppm for NO. Total dust samples were collected on polyvinyl chloride filters with a pore size of 0.8 µm (Omega Specialty Instrument Co., Chelmsford, MA), using high-volume pumps (Gilian Instrument Corp., Wayne, NJ) and quantified by gravimetry. The detection limit and total coefficient of variation for this method was 25 µg and < 7%, respectively. The flow rate of the sampling pumps was approximately 2 l/min and sampling times were approximately one hour per filter. Flow rates were measured on-site using a Kurz precalibrated flowmeter (Kurz Instruments Inc., Carmel Valley, CA).

Results are presented as mean ± standard deviation (SD) and because the data were best described by a normal distribution, means have been compared by Student's t-test.

RESULTS AND DISCUSSION

Tables 1 to 3 present the results of air sampling analysis. Among other things, Tables 1 and 2 contain statistically significant differences ($p \leq 0.05$) between the average indoor concentrations and those found 300 metres upwind from the plant, for the evaluations carried out in summer.

Total bacteria. In summer, in the reception areas and fermentation buildings of the two centers, the average total bacteria concentrations were greater than the suggested average level of 10,000 cfu/m^3 of air for this

Table 2. Average concentrations of biological contaminants (± standard deviation) in center B.

Contaminant			Total bacteria		Gram neg.		Thermoactino.		A. *fumigatus*		Molds
Guidelines*			10,000		1,000		-		-		-
		n	cfu/m^3	n	cfu/m^3	n	cfu/m^3	n	cfu/m^3	n	cfu/m^3
Upwind	Summer	6	870 (380)	6	20 (1)	3	60 (40)	6	20 (1)	3	1,690 (60)
	Winter	N.m.	N.m.		N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.
Downwind	Summer	6	1,710[a] (430)	6	20 (1)	6	30 (10)	6	20 (1)	4	1,600 (60)
	Winter	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.	N.m.
Control room	Summer	6	6,580[a] (1,000)	6	30 (10)	3	3,930[a] (1,340)	2	110[a] (50)	3	1,000 (180)
	Winter	6	9,970 (3,520)	6	N.d.	4	200 (90)	6	175 (90)	4	1,100 (60)
Reception	Summer	5	14,290[a] (9,290)	6	190[a] (180)	5	3,720[a] (1,550)	3	60[a] (40)	5	2,330 (1,460)
	Winter	5	27,000 (7,160)	6	410 (210)	4	80 (30)	5	2,980 (460)	5	11,900 (460)
Fermentation	Summer	6	87,020[a] (1,070)	3	200[a] (110)	6	15,000[a] (150)	5	310[a] (190)	6	10,540[a] (1,720)
	Winter	3	11,350 (900)	6	10 (20)	4	110 (60)	4	200 (60)	4	340 (175)

[a]Average concentrations significantly greater ($p \leq 0.05$) than those in the upwind outdoor air; N.m.: Not measured; N.d.: Not detected; *Recommended guidelines [24, 25, 31].

type of activity. Respectively, they were 53,690 (±16,000) cfu/m^3 and 168,440 (±2,270) cfu/m^3 of air for center A, and 14,290 (±9,270) cfu/m^3 and 87,020 (±1,070) cfu/m^3 of air for center B. During the winter, they were greater at the same locations for center B, with 27,000 (±7,160) cfu/m^3 and 11,350 (±900) cfu/m^3 respectively, and greater only in center A's reception area with 68,920 (±20,340) cfu/m^3 of air. Waste and compost storage appears to be a major source of total bacteria, regardless of the season.

Gram-negative bacteria. When average concentrations are compared to the recommended level of 1,000 cfu/m^3 of air, none of the sampling stations exceeded this value, regardless of the season. The way the operations are carried out, it appears that emission into the air of this type of microorganism and possibly its toxins can be controlled.

Thermophilic actinomycetes. The average temperature of the compost is an ideal climate for thermophilic bacteria to proliferate [14, 19, 22, 24, 25]. The maximum average concentration in this study was 15,000 (±150) cfu/m^3 of air, measured during the summer in center B's fermentation building. In contrast to total bacteria and Gram-negative bacteria, there are no suggested exposure levels for this type of microorganism. In other types of environments such as mushroom growing, concentrations of thermoactinomycetes of 10^5–10^7 cfu/m^3 of air have been measured [8, 13]. According to Miller [28], concentrations in the order of 10^8 cfu/m^3 of air are necessary for the development of acute symptoms. In several studies on composting, exposures to thermoactinomycetes are in the range of 10^5–10^8 cfu/m^3 of air, and Lacey *et al.* [14, 31] have suggested that exposures greater than 10^6 cfu/m^3 of air would produce an increased risk of extrinsic allergic alveolitis and ODTS.

Table 3. Average concentrations of chemical contaminants (± standard deviation) in the fermentation departments of centers A and B.

Contaminant			TPM[a]		CO_2		NH_3		N_2O		CO		H_2S		NO		NO_2
Standards			10		5000		25		50		35		10		25		5
		n	mg/m^3	n	ppm	n	ppm	n	ppm	n	ppm	n	ppm	n	ppm	n	ppm
Centre A																	
Fermentation	Summer	9	0.8 (0.1)	33	1,740 (440)	32	20 (6.5)	33	2.0 (0.5)	33	1.2 (1.0)	20	7.8 (1.1)	33	0.5 (0.5)	66	0.1 (0.1)
	Winter	5	0.37 (0.1)	42	4,030 (540)	42	20.6 (1.5)	43	6.2 (0.9)	41	7.3 (1.6)	17	3.5 (0.5)	60	N.d.	60	N.d.
Centre B																	
Fermentation	Summer	7	0.3 (0.04)	23	575 (60)	21	8.1 (2.7)	20	0.9 (0.1)	21	0.5 (0.3)	17	N.d.	56	N.d.	34	N.d.
	Winter	14	0.1 (0.1)	30	1,020 (130)	30	3 (0.6)	30	1.9 (0.2)	30	1.0 (0.1)	30	N.d.	30	N.d.	30	N.d.

[a]Total Particulate Matter; N.d.: Not detected.

Aspergillus fumigatus. This species of thermoresistant mold is mainly encountered when there is compost or substrates with a temperature greater than or equal to 45°C, such as in farms where moldy hay is stored [13, 21, 22, 25, 28]. The precise dose that produces health effects in healthy or sensitized exposed individuals is not yet known [27, 28, 34]. Clark *et al.* [6] measured concentrations of this mold in the order of 10^6 cfu/m^3 of air in some composting plant departments. In this study, a maximum average concentration of 12,000 (±2,900) cfu/m^3 of air was measured in winter in center A's fermentation building. Also, during the summer, significantly higher average concentrations ($p \leq 0.05$) than upwind in the outdoor air were measured at all workstations in both centers. However, these concentrations remain low when compared to those found in the scientific literature on this type of plant.

Molds. Molds were present at average concentrations varying from 60 (±20) cfu/m^3 of air in center A's sorting area during the summer, to 14,380 (±730) cfu/m^3 of air in the reception area of the same center during the winter. Concentrations in the order of 10^2-10^6cfu/m^3 of air have been measured in other studies on composting centers [31]. In another Quebec study in a composting center, Marchand *et al.* [26] measured concentrations of molds in the order of 10^3 cfu/m^3 of air. Exposure to mold spores has been linked to allergic alveolitis and ODTS [10].

Due to the high concentrations of total bacteria and the presence of molds, thermoactinomycetes and *A. fumigatus*, it has been suggested that a breathing mask that is effective against dusts larger than one micron and that has a layer of active carbon to eliminate odors should be worn in the fermentation building and in the reception area. It would also be preferable to use disposable masks to avoid the proliferation of organisms when the masks are not being worn.

Finally, at the microbial level, outdoor air quality 100 metres downwind does not seem to be affected by the operations carried out in these two centers.

Chemical contaminants. Gaseous and particulate contaminants were measured in the fermentation buildings of the two centers (Tab. 3). For center B, the average concentrations were all below 50% of their regulated exposure value, regardless of the season [32]. At center A, the average concentrations were greater than 50% of their regulated exposure value for hydrogen sulfide and ammonia during the summer, and for carbon dioxide and ammonia during the winter. According to the American Conference of Governmental Industrial Hygienists (ACGIH), NH_3 is a colorless and very irritating gas [1]. H_2S is also colorless and has an odor of rotten eggs [1]. It has been suggested that the three exhaust fans should be operating when the windrows are turned in order to dilute these concentrations.

CONCLUSIONS

The average concentrations of total bacteria in the reception areas and in the fermentation buildings of the two centers were greater than the suggested level of 10,000 cfu/m^3 of air. Waste and compost storage therefore appears to be a major source of bacteria. For Gram-negative bacteria, none of the workstations, regardless of the season, exceeded the suggested exposure level.

The maximum average concentration of thermo-actinomycetes of 15,000 (±150) cfu/m^3 of air, measured during the summer at center B, does not appear to produce health effects in the workers, according to the literature consulted. A maximum average concentration of 12,000 (±2,900) cfu/m^3 of *A. fumigatus* in the air was measured in winter in center A's fermentation building. The precise dose that produces health effects in workers does not appear to be known. The average concentrations measured in this study are nevertheless low when compared to those found in the scientific literature on this type of activity. Molds were present at average concentrations varying from 60 (±20) cfu/m^3 of air to 14,380 (±730) cfu/m^3 of air. Concentrations in the order of 10^2–10^6 cfu/m^3 have already been measured in other studies on composting.

Due to the high concentrations of total bacteria and the presence of thermoactinomycetes, *A. fumigatus* and molds, it has been suggested that effective respiratory protection should be worn in the fermentation buildings and the reception areas of both plants.

In center B, the chemical contaminants were below 50% of their regulated exposure value, regardless of the season. In center A, some contaminants such as ammonia, hydrogen sulfide and carbon dioxide exceeded this level. It has been suggested that all exhaust fans should be operating when the windrows are turned in order to dilute the concentrations of these contaminants.

Finally, outdoor air quality at the microbial level does not appear to be affected by the operations carried out in these centers.

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