Biological and chemical contamination of the air in a grower-finisher pig building using deep-litter systems

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Lavoie, J., Marchand, G., Drolet, J.-Y. and Gingras, G. **Biological and chemical contamination of the air in a grower-finisher pig building using deep-litter systems.** Can. Agric. Eng. 37:195-203. Conventional pig-housing facilities expose farmers to high concentrations of microorganisms, organic dusts, and gases, all of which are suspected of causing health problems. A recent method of growing-finishing has been developed which relies upon the use of biotreated litter, i.e. litter composed of solid waste, sawdust or straw, and a biotechnologically produced enzyme that acts on ammoniacal nitrogen in pig manure to stimulate fermentation. The surface of the litter is stirred once a week to maintain aerobic conditions within the litter. The deep-litter method is supposed to produce compost which can be used to improve the physical, chemical, and biological properties of soil. This project was undertaken to measure the chemical and biological contaminants present in the air of a grower-finisher pig building using the deep-litter method and assess the safety of these workplaces for workers. While the concentrations of contaminants usually found in pig-housing facilities, such as Gram-negative bacteria and gases, were within acceptable limits, this type of facility offers ideal conditions for the proliferation of thermophilic actinomycetes and *A. fumigatus*. Given the unresolved risks associated with thermophilic actinomycetes and *A. fumigatus*, it is recommended that workers in this environment wear HEPA-equipped (High Efficiency Particulate Air Filters) masks capable of capturing 99.7% of the spores.

Les méthodes habituellement utilisées dans l'élevage du porc exposent les éleveurs à des concentrations élevées de microorganismes, de poussières organiques et à des gaz, tous soupçonnés d'être la cause de plusieurs problèmes de santé. Récemment, un nouveau type d'élevage pour les porcs a fait son apparition. Il s'agit de l'élevage sur litière biomaîtrisée, i.e. une litière composée d'un mélange de déjections solides, de sciures de bois ou de paille et d'une enzyme issue de la biotechnologie. Une fois par semaine, pour obtenir des conditions aérobiques, l'aération est réalisée par un brassage de la surface de la litière. De plus, le compost produit semblerait améliorer les propriétés physico-chimiques et biologiques du sol. Les objectifs de ce projet étaient de mesurer les contaminants chimiques et biologiques présents dans l'air d'une porcherie utilisant la technique de la litière biomaîtrisée dans le but de démontrer à quel niveau se situe la salubrité de ce milieu de travail pour les travailleurs. Ce type d'élevage permet de réduire les concentrations des contaminants habituellement retrouvés dans les porcheries comme les bactéries Gram négatives et les gaz à des niveaux acceptables. Par contre, ce nouveau type d'élevage possède les conditions idéales pour assurer le développement des thermoactinomycètes et de la moisissure A.fumigatus. Considérant les risques encore existant, il est suggéré, pour protéger la santé des travailleurs de ce milieu de porter des masques de protection respiratoire munis de filtres HEPA (High Efficiency Particulate Air-Filters) assurant une retention de 99,7% des spores.

INTRODUCTION

Modern pig-housing facilities were designed to facilitate the distribution of food, the administration of medication, and waste-cleaning operations in confined spaces. Unfortunately, these confined spaces also result in worker exposure to high concentrations of microorganisms, organic dusts, and gases, all of which are suspected of causing health problems (Donham and Gustafson 1982; Rylander 1985; Donham 1986a, 1990; Donham et al. 1989; Dosman and Cockcroft 1989; Cormier et al. 1990; Cormier 1991). Reduction of exposure to chemical and biological contaminants is therefore an ongoing concern in these environments. The installation of effective ventilation systems proposed by Harry (1978), Barber (1986), Clark (1986), Donham (1986a) and Cormier et al. (1990), particularly of base-exhaust systems (Gingras and Lavoie 1991), has been suggested as a means of controlling the concentration of microorganisms. However, previous studies of ventilation in pig-housing facilities observed Gram-negative bacteria concentrations well above recommended limits, despite significant reductions of the concentration of other biological and chemical contaminants (Ludholm and Rylander 1980; Clark 1984, 1987; Gingras and Lavoie 1991).

Recently, a new pig-breeding method based on the use of a biotreated litter, i.e. litter composed of solid waste, sawdust or straw, and a biotechnologically produced enzyme, has appeared in Europe (Chatillon and Viel 1990). The enzyme is supposed to increase the activity of bacteria that occur naturally in pig manure and thereby accelerates the degradation of cellulose and lignin contained in sawdust, straw, and solid waste (Viel 1991). The litter itself contains magnesium, potassium, sodium, calcium, phosphoproteins and vitamins B1 and B2, all elements normally found in microbial culture media and in fertilizers (Viel 1991). According to Viel (1991), the heat generated by this reaction (30-60°C, depending on the dose and substrate), has the following beneficial effects :

1. The litter is dried almost instantaneously, eliminating liquid effluents.

2. Many of the most dangerous germs are destroyed.
3. The bacteria capture all the nitrogen in the solid waste before it can be emitted, thus reducing the emission of gases which can affect the health of animals and workers.

According to Viel (1991), the enzyme must be incorporated in a layer of sawdust or chopped straw 600 mm thick. This layer rests on 100-150 mm of pig manure mixed homogenously with chopped straw or sawdust. The enzyme is supposed to act on ammoniacal nitrogen in pig manure and stimulates fermentation (Tam and Vrijmoed 1990). In well-aerated and well-ventilated litter, the heat generated is supposed to be proportional to the amount of manure (Viel 1991). Once a week, the litter is aerated by stirring its surface, and accumulated solid waste sprayed with the enzyme and buried in the litter (Caouette et al. 1992). The method is also supposed to have the advantage of allowing several groups of pigs to be raised on the same litter. Navarotto and Bonazzi (1990) reported that the litter must be changed every 12 months, reducing the volume of manure by 75% compared to conventional methods. The compost produced is supposed to be a high-quality soil supplement (Navarotto and Bonazzi 1990). By eliminating odours and substantially reducing manure volume, Chatillon and Viel (1990) reported that the deep-litter method causes fewer environmental problems and could prove to be superior to currently used conventional pig-breeding practices.

This project was undertaken to measure the chemical and biological contaminants present in the air of a grower-finisher pig building using the deep-litter method and assess the safety of these workplaces for workers.

METHODOLOGY

The facility's layout is illustrated in Fig. 1. The grower-finisher pig building under study was constructed specifically for the implementation of the deep-litter method. The galvanized steel frame sits on concrete walls 1.22 metres high. The walls within the steel-framed section are constructed of a double thickness of polyethylene on a thin and flexible layer of Astro-Foil™ insulation (BPR Consultants 1994). This material is the insulation of choice for greenhouse siding, as it is capable of limiting condensation in humid environments such as these, despite its low thermal insulation factor (R_{si}=1.45 $m^2 \cdot {}^{\circ}C/W$) (BPR Consultants 1994).

The facility has a capacity of 120 pigs and is divided into 6 pens of 26 m^2 each (1.3 m^2 per pig). The total interior volume is approximately 1200 m^3, or 10 m^3 per pig. The facility is separated from other farm buildings, facilitating the control of ambient conditions and measurement of parameters such as energy demand and water consumption.

Each pen contains 20 pigs and is equipped with a double trough from which animals receive water and wet feed. The first group of pigs was started in mid-November of 1992. On average, pigs have a mass of 20 kg on entering the facility, and leave 119 days later (average of 3 groups) at 80 kg (BPR Consultants 1994). The winter evaluation conducted for this study observed the second group, with an average mass of 36 kg per pig while the summer evaluation observed the final stages of the fattening of the third group, with an average mass of 44 kg per pig.

In the winter, ventilation is provided by two variable-speed fans 350 mm in diameter, located in the middle of the side walls, which draw and distribute air through perforated plastic ducts running the length of the facility. Air is exhausted through a duct 600 mm in diameter located in the centre of the ceiling, also running the length of the facility. In summer, the same ventilation system is used, but two doors measuring 3 x 3.65 m and covered by polyethylene mesh (porosity 35%) are also opened. The ventilation system has a capacity approximately twice that of systems found in conventional facilities. This higher capacity is necessary because of the large quantities of water produced from fecal matter and urine and the heat generated by fermentation. Water balance calculations were used by BPR Consultants (1994) to determine the equilibrium point, i.e. the point at which the rate of removal of moisture from the litter is equal to the rate of water production from feces and urine. In light of these calculations, ventilation capacity was increased to approximately 45 m^3/h per pig (12.5 L/s per pig), which had significant effects on heating requirements.

On the other hand, unit setup costs are lower with this type of facility, as internal infrastructures are less sophisticated (absence of slat floors, furrows, and manure pits) (BPR Consultants 1994). BPR Consultants (1994) have reported that deep-litter facilities require a slightly lower initial investment than do conventional facilities despite requiring a greater surface area per pig, since the internal layout is simpler and manure reservoirs are not needed. While deep-litter facilities incur additional costs related to litter, enzyme, heating, and labour, these appear to be compensated for by reductions in manure disposal costs (stirring, pickup, transport, spreading). In fact, the financial advantage of deep-litter production over conventional production increases as the average distance over which manure must be spread increases (BPR Consultants 1994).

Ventilation rates were calculated using a digital vane anemometer (Model DA4000, Pacer Industries Inc., Chippewa, WI) located in the centre of the exhaust duct, 3 m from the exit fan. The anemometer had a precision of ± 0.5% of readings and was connected to a data collection module (Model DLX-100, D.E.S. Corporation, Québec, QC).

Facility heating was provided by a 17.5 kW ambient-air pre-heating unit and a supplemental 44.4 kW propane-fired radiant heat heating unit.

The recommended levels of enzymes were adjusted to suit operating conditions. The waste over one-quarter of each pen was stirred and buried every week (5 m^2). A rototiller was then used to homogenize the first 300 mm of the litter, and sawdust was added as required. The following enzymes were used: Sef-C (Nissan, Japan), 4 mL/1200 ml water in pens 1 and 2, Biolyse (TBA, Saint-Maur, France) 20 mL/600 ml water in pens 3 and 4 (20 pigs), and Lobiflor (Laboratoires Lobial, Laval, France) 135 g/m^2 in pens 5 and 6 (Fig. 1).

The following chemical and biological contaminants, commonly found in pig housing facilities and composting facilities, were sampled: nitrogen oxides (NO, NO_2, N_2O), carbon dioxide (CO_2), ammonia (NH_3), hydrogen sulphide (H_2S), total dust, total bacteria, Gram-negative bacteria, thermophilic actinomycetes, total moulds, and *Aspergillus fumigatus*.

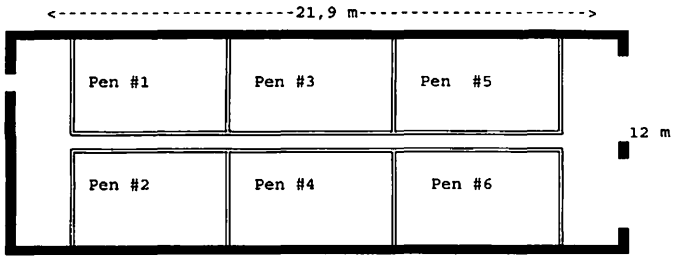

Fig. 1. Layout of the facility.

Gases were measured in the center of the facility at 1.5 m height with direct-reading monitors connected to a data collection module (Model DLX-100, D.E.S. Corporation, Québec, QC). N_2O, NH_3, CO_2, and CO were measured with a multi-gas photoacoustic spectroscopic monitor (Model 1302, Bruël and Kjaer, Pointe-Claire, QC) 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. Carbon dioxide was also measured using an infra-red spectrophotometer (Model ADC-PM3, The Analytical Development Co. Ltd., Hoddesdon, England) with a detection limit of 10 ppm. Hydrogen sulphide was measured with an electrochemical monitor (Model 4173, Interscan Corp., Chatsworth, CA) with a detection limit of 0.4 ppm. Nitrogen oxides (NO and NO_2) were measured with an electrochemical monitor (Ecolyser 7000, Dräger, Lübeck, Germany) with a detection limit of 0.4 ppm for NO and 0.04 ppm for NO_2. Total dust samples were collected on polyvinyl chloride filters with a pore size of 0.8 μm (Omega Speciality Instrument Co., Chelmsford, MA), using high-volume pumps (Gillian 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 (NIOSH 1977). 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). A minimum of 14 dust samples at the same location in the center of the facility were taken before stirring and approximately the same number taken afterwards.

Microorganisms were sampled using microbial impacters (Andersen Instruments Inc., Atlanta, GA) with a precision of ± 7% under laboratory conditions (Jansen et al. 1992). Duplicate samples were taken simultaneously for each type of sample. The sampling time for total bacteria was 15 seconds in winter and 30 seconds in summer. A sampling time of one minute was for all other samples. A minimum of 32 samples was taken for each type of microorganism during each of the two seasons, in an attempt to sample continuously throughout the 4-hour observation period. The following incubation media were used:

- SDA (Sabouraud dextrose agar, Quelab Laboratories, Montréal, QC). Total mould samples were incubated for 7 days at ambient temperature. *Aspergillus fumigatus* samples were incubated for 7 days at 45°C.
- TSA (trypticase soya agar, Quelab Laboratories, Montréal, QC). Total bacteria samples were incubated for 48 hours at 35°C. Thermophilic actinomycetes samples were incubated for 48 hours at 55°C.
- MacConkey medium (Quelab Laboratories, Montréal, QC). Gram-negative bacteria were incubated for 48 hours at 37.5°C.

Contact thermometers (MPM 500, Solomat Corp., Stanford, CT) were used to measure litter temperature in the four corners of the pens at two depths, i.e., 300 and 600 mm. (Table II). The precision of these thermocouples was ± 0.1%. Indoor and outdoor temperatures were measured using thermistors (Yellow Spring Instruments Co., Yellow Spring, OH) (Table I). The precision of these instruments was ± 0.5°C.

Winter sampling began in March. Samples were taken before and after stirring operations (approximately 2 hours per operation), for a total of 4 hours of sampling. Data on temperature, humidity, static pressure, and the concentration of chemical contaminants were collected at 1-minute intervals. A second sampling series was performed at the beginning of the summer, using the same sampling strategy, to assess the effect of differing atmospheric conditions. The summer group used the same sawdust litter as the winter group.

Student's t-test was used, because the data were best described by a normal distribution, to compare the mean concentrations before and during stirring, and determine whether any seasonal effects were present (Scherrer 1984).

Contaminant concentrations were compared with proposed standards, where these existed, or with contaminant concentrations reported in studies of pig-housing or composting facilities. Final conclusions concerning the safety of the environment for workers were based on these comparisons.

Table I: Mean air temperature (°C), relative humidity, and ventilation rates

	Temperature (°C)				Relative Humidity (%)				Mean ventilation rate (m^3/s)
	n	Inside	n	Outside	n	Inside	n	Outside	
Winter (03-93)	37	17.1 (±0.8)	37	-13.1 (±1.8)	35	75.1 (±1.4)	35	34.0 (±2.2)	1.1 (±0.3)
Summer (07-93)	30	27.8 (±1.0)	30	26.6 (±1.0)	30	66.8 (±4.9)	30	64.7 (±5.9)	1.9 (±0.9)

Table II. Mean litter temperature[1]

	Temperature (°C)			
	Winter		Summer	
	300 mm	600 mm	300 mm	600 mm
Pen # 1	35.3 (± 6.8)	37.5 (± 0.7)	49.7 (± 3.3)	50.4 (± 1.7)
Pen # 2	33.5 (± 2.4)	47.5 (± 0.7)	41.7 (± 2.7)	41.6 (± 1.6)
Pen # 3	43.5 (± 2.4)	49.5 (± 0.7)	44.8 (± 5.0)	45.0 (± 4.4)
Pen # 4	41.0 (± 3.8)	40.5 (± 0.6)	47.8 (± 1.6)	44.2 (± 2.1)
Pen # 5	44.0 (± 3.2)	53.5 (± 0.7)	45.7 (± 3.8)	47.1 (±4.1)
Pen # 6	43.7 (± 8.4)	56.6 (± 2.3)	42.7 (± 1.2)	42.3 (± 0.9)

[1] Mean of four readings

RESULTS AND DISCUSSION

Table I lists the average air temperature, relative humidity levels, and ventilation rates measured during the two sampling series. Table II lists the average litter temperature at depths of 300 and 600 mm in summer and winter. The air sampling results are presented in Tables III and IV. The results obtained for each contaminant are discussed below.

Total bacteria

The concentration of total bacteria well exceeded levels recommended for composting facilities (including those composting manure). The highest average concentration was 2.7 x 10^5 Colony Forming Units/m^3 of air (CFU/m^3), measured during litter stirring in the winter. This is 27 times the proposed exposure limit of 10^4 CFU/m^3 proposed by Malmros (1990) and Malmros et al. (1992) (Tables III and IV). Donham et al. (1989), in Sweden, have reported average concentrations of 1.4 x 10^6 CFU/m^3 in pig-housing facilities and Crook et al. (1991), in their survey of six pig-housing facilities in the United Kingdom, observed concentrations of total bacteria of 3-80 x 10^5, 2-60 x 10^5, and 2-20 x 10^3 CFU/m3 in samples incubated at 25°, 37°, and 55°C. In another Swedish study, Clark et al. (1983a) reported a median concentration of total bacteria of 3 x 10^5 CFU/m^3 at six farms. Atwood et al. (1987) reported a maximum concentration of total bacteria of 3 x 10^6 CFU/m^3 in their survey of 171 Dutch pig-housing facilities. In a survey of 30 American pig-housing facilities, Donham (1986a) reported an average total bacteria concentration of 3 x 10^6 CFU/m^3 and a statistically significant association between exposure to concentrations of at least 1.4 x 10^6 CFU/m^3 and the prevalence of noisy breathing and frequent chest colds in workers. It is important to note, however, that these studies used a variety of sampling methods. A Québec study carried out by Cormier et al. (1990), using the same sampling methods as those in this study, reported average concentrations of 1.67 x 10^5 CFU/m^3, which is comparable to those reported by other authors. The concentration of total bacteria observed in the present study therefore appears to be comparable to those reported for conventional pig housing facilities.

Gram-negative bacteria

Endotoxins liberated by the cell walls of Gram-negative bacteria may cause a wide variety of symptoms, including fever, diarrhea, and gastrointestinal and respiratory problems, in exposed humans (Lundholm and Rylander 1980; Clark 1984, 1987; Malmros 1990; Laitinen et al. 1992; Malmros et al. 1992).

The concentration of Gram-negative bacteria in the winter sampling series exceeded the 10^3 CFU/m^3 limit recommended by Malmros (1990) and Malmros et al. (1992) for waste-treatment and composting facilities (Table III). The maximum concentration was 3.8 x 10^3 (± 1.2 x 103) CFU/m^3, observed after litter stirring. In Donham's study (1986a) of 30 pig-housing facilities, the average concentration of Gram-negative bacteria reported was 8.8 x 10^4 CFU/m^3, while Atwood et al. (1987), in their study of 171 pig-housing facilities, reported average concentrations of Gram-negative bacteria of 10^4 CFU/m^3. Various authors have claimed that Gram-negative bacteria represent 1-10% of the total bacteria count in this type of environment (Clark et al. 1983a; Donham 1986a, 1986b; Attwood et al. 1987). Summer levels of Gram-negative bacteria were below this level and in fact below recommended limits.

Thermophilic actinomycetes

With temperatures between 33.5-56.6°C in winter and 41.6-50.4°C in summer (Table II), the deep-litter method provides an ideal environment for the proliferation of thermophilic bacteria such as thermophilic actinomycetes (Lundholm and Rylander 1980; APHA 1985; Lacey and Crook 1988; Malmros 1990; Tam and Vrijmoed 1990; Crook et al. 1991; Crook 1992; Lessard 1992; Malmros et al. 1992; Maritato et al. 1992; Miller 1992). There is no recommended exposure limit for these bacteria, in contrast to total bacteria and Gram-negative bacteria (Lacey and Crook 1988; ACGIH 1993). The highest average concentration of thermophilic actinomycetes observed in this study was 3.5 x 10^3 (± 2.0 x 10^3) CFU/m^3, observed in the winter after litter stirring (Table III).

Thermophilic actinomycetes cause hypersensitivity pneumonitis (allergic alveolitis, farmer's lung) (APHA 1985; Lacey and Crook 1988; Shellito 1991; Miller 1992). Concentrations of 10^5-10^7 CFU/m^3 have been measured in other environments by Lacey and Crook (1988) and Crook (1992), e.g. mushroom farming, where exposure may cause respiratory sensitization. Miller (1992) believes that concentrations of the order of 10^8 CFU/m^3 are necessary for the development of acute symptoms. Recently, Crook (1992) found that this type of bacteria can cause allergic respiratory responses in individuals exposed to concentrations of 10^3 CFU/m^3 in pig-housing facilities. Average concentrations observed in the present study are of approximately the same magnitude, i.e. 3.8 x 10^3 CFU/m^3.

Aspergillus fumigatus (thermotolerant)

A. fumigatus may cause symptoms ranging from allergic responses to chronic respiratory diseases in individuals with

Table III. Contaminant concentrations (Winter)

Contaminant	Exposure limit or recommended value	Before stirring		After stirring	
		n	mean (standard deviation)	n	mean (standard deviation)
Total bacteria (CFU/m^3)	10 000 CFU/m^3 †	19	172 800 (± 53 920)	18	266 800* (± 98 850)
Gram-negative bacteria (CFU/m^3)	1 000 CFU/m^3 †	20	2 990 (± 2 200)	19	3 840 (± 1 180)
Thermoactinomycetes (CFU/m^3)	-	17	2 570 (± 1 920)	20	3 450 (± 2 000)
Moulds (CFU/m^3)	-	16	3 350 (± 430)	17	6 310* (± 1 850)
Aspergillus fumigatus (CFU/m^3)	-	18	1 220 (± 780)	15	1 080 (± 690)
Total dust (mg/m^3)	10 mg/m^3 ‡	17	0.5 (± 0.1)	16	0.5 (± 0.1)
Carbon dioxide (CO_2) (ppm)	5 000 ppm ‡	63	2 370* (± 140)	41	2 150 (± 150)
Ammonia (NH_3) (ppm)	25 ppm ‡	60	4.4 (± 1.5)	40	4.8 (± 1.1)
Nitrous oxide (N_2O) (ppm)	50 ppm ‡	63	12.5 (± 0.9)	41	11.8 (± 1.5)
Carbon monoxide (CO) (ppm)	25 ppm ‡	63	7.2 (± 0.5)	41	34.7* (± 19.8)
Nitric oxide (NO) (ppm)	25 ppm ‡	22	0.3 (± 0.15)	16	0.3 (± 0.13)
Nitrogen dioxide (NO_2) (ppm)	3 ppm ‡	20	0.7 (± 0.3)	16	1.5* (± 0.4)

* $p \leq 0,05$
† Malmros (1990); Malmros et al. (1992).
‡ ACGIH (1993).

a compromised immune system (APHA 1985; Maritato et al. 1992), and is the cause of Aspergillosis (APHA 1985; Miller 1992). This thermotolerant mold is especially prevalent in environments such as silos containing mouldy hay, in which substrates such as compost are maintained at temperatures of at least 45°C (Lundholm and Rylander 1980; Lacey and Crook 1988; Crook 1992; Lessard 1992; Malmros et al. 1992; Maritato et al. 1992; Miller 1992). According to a working group on the effects of fungi in indoor air (Santé et bien-être Social du Canada 1987), *A. fumigatus* is a potential human health hazard, since it is allergenic and pathogenic and produces potent mycotoxins. The same group considers exposure to this mold to be a serious health concern. *A. fumigatus* is also associated by Lacey and Crook (1988) with occupational asthma, especially in mushroom farms using compost substrates. The precise dose causing health effects in humans is currently unknown (Santé et bien-être social du Canada 1987; Maritato et al. 1992; Miller 1992). Clark et al. (1983b), in their study of Swedish composting facilities, measured concentrations of approximately 10^6 CFU/m^3 of *A. fumigatus* at certain departments. *A. fumigatus* is not commonly found in ambient air (Millner et al. 1977). Although low levels of *A. fumigatus* in outdoor air do not appear to cause infection in healthy individuals, concentrations of 10-10^4 CFU/m^3 may be allergenic in sensitized individuals (Millner et al. 1977). The maximum level found in this study was 9.4 x 10^3 (± 5.4 x 10^3) CFU/m^3, observed in the summer following litter stirring (Table IV).

Molds

Mold concentrations varied from 3.4 x 10^3 (± 4.3 x 10^2) to 8.7 x 10^3 (± 3.5 x 10^3) CFU/m^3 (Tables III and IV), with the highest average concentration (8.7 x 10^3 (± 3.5 x 10^3) CFU/m^3) measured in the summer (Table IV). In winter, when outdoor concentrations of molds were essentially zero due to snow cover (Santé et bien-être social du Canada 1987; ACGIH 1989; Miller 1992), a concentration of 6.3 x 10^3 (± 1.9 x 10^3) CFU/m^3 was observed after litter stirring (Table III). Concentrations of this magnitude were often reported in pig housing facilities by Donham and Gustafson (1982), Clark et al. (1983a), Donham (1986a, 1986b, 1990), Donham et al. (1989), Crook et al. (1991), and Crook (1990). A Swedish study carried out by Donham et al. (1989) of the effect of environmental factors on the health of workers in pig-housing facilities reported an statistically significant association between concentrations of at least 1.3 x 10^4 CFU/m^3 and respiratory symptoms. The ACGIH (1989) considers concentrations less than 10^2 CFU/m^3 unlikely to be harmful except in immunodeficient individuals.

Exposure to mold spores has been associated with allergic alveolitis and toxic organic dust syndrome by Eduard et al. (1993). Inhalation of fungal spores and propagules may cause

Table IV: Contaminant concentrations (Summer)

Contaminant	Exposure limit or recommended value	Before stirring		After stirring	
		n	mean (standard deviation)	n	mean (standard deviation)
Total bacteria ($CFU/^3$)	10 000 CFU/m^3 †	20	78 200 (± 26 300)	20	146 100* (± 44 300)
Gram-negative bacteria (CFU/m^3)	1 000 CFU/m^3 †	20	490 (± 365)	19	495 (± 210)
Thermoactinomycetes (CFU/m^3)	-	22	1 410 (740)	22	2 790* (± 820)
Moulds (CFU/m^3)	-	18	5 570 (± 3 450)	18	8 740* (± 3 530)
Aspergillus fumigatus (UFC/m^3)	-	18	1 520 (± 1 310)	14	9 420* (± 5 440)
Total dust (mg/m^3)	10 mg/m^3 ‡	14	0.3 (± 0.1)	18	0.4* (± 0.1)
Carbon dioxide (CO_2) (ppm)	5 000 ppm ‡	35	730 (± 160)	36	795 (± 190)
Ammonia (NH_3) (ppm)	25 ppm ‡	36	0.9 (± 0.3)	37	1.3 (± 0.4)
Nitrous oxide (N_2O) (ppm)	50 ppm ‡	35	2.2 (± 0.6)	37	2.8* (± 1.3)
Carbon monoxide (CO) (ppm)	25 ppm ‡	41	1.0 (± 0.2)	29	11.0* (± 15.6)
Nitric oxide (NO) (ppm)	25 ppm ‡	-	N.D.	-	N.D.
Nitrogen dioxide (NO_2) (ppm)	3 ppm ‡	-	N.D.	-	N.D.

* $p \leq 0{,}05$
† Malmros (1990); Malmros et al. (1992).
‡ ACGIH (1993).

effects other than allergic reactions (Santé et bien-être social du Canada 1987). The term pulmonary mycotoxicosis has been used to refer to a group of diseases caused by mycotoxins, endotoxins, and other factors. The extent to which the presence of mycotoxins contributes to the ability of inhaled fungal spores or propagules to cause this disease and the effects of inhalation of volatile fungal products on human health are unknown (Santé et bien-être social du Canada 1987).

Gases

In both sampling series, the concentration of chemical contaminants was always less than 50% of their exposure limit prescribed by the United States's ACGIH (Tables III and IV) (ACGIH 1993). Donham et al. (1989) reported respiratory problems in pig-housing workers exposed to at least 7 ppm of ammonia and 3.8 mg/m^3 of dust. In this study, the maximum ammonia concentration was 4.8 ppm after litter stirring in winter and the dust concentrations were always less than 0.5 mg/m^3.

Stirring had statistically significant effects ($p \leq 0.05$) on the concentration of total bacteria, molds, CO, and NO_2 in the winter, and on total bacteria, thermophilic actinomycetes, molds, *A. fumigatus*, N_2O, and CO during the summer (Tables III and IV). The significantly higher concentrations of CO in winter and summer and of NO_2 in the winter observed after litter stirring may be due in part to the use of a gas-powered rototiller to perform this operation. It is not surprising that the other contaminants were found at significantly higher concentrations after stirring, given their origin in the litter.

BPR Consultants (1994) have reported that the litter temperature in all the pens over an 11-month period was 30-50°C, regardless of sampling depth. These results are similar to those reported by Bonazzi and Navratto (1992), who measured litter temperatures of 35-45°C at a depth of 200 mm. The composting process is fed by the continual addition of litter and waste and the temperature does not therefore follow a growth curve. The true thermophilic phase is either very short or absent and the litter does not undergo a sterilization process that would destroy the majority of pathogenic microorganisms. Crook (1992) and Lessard (1992) recommend maintaining litter at a temperature of 60-70°C for at least a week, to reduce the concentration of total bacteria, Gram-negative bacteria, and thermophilic actinomycetes. These temperatures can never be achieved at the surface of deep-litter facilities, since incoming air cools the litter. This cooling creates conditions favourable to the proliferation of thermophilic actinomycetes and thermotolerant moulds such as *A. fumigatus*.

The concentration of contaminants commonly found in pig housing facilities, such as Gram-negative bacteria and gases, remains at acceptable levels in deep-litter facilities equipped with adequate ventilation systems. The method has other

significant effects, including the elimination of manure pits and leachate, and the reduction of manure volume by 75% compared to conventional facilities (BPR Consultants 1994).

However, the deep-litter method also provides ideal conditions for the proliferation of *Aspergillus fumigatus*, an allergen and source of chronic respiratory problems, and of thermophilic actinomycetes that cause hypersensitivity pneumonitis (APHA 1985; Lacey and Crook 1988; Shellito 1991; Maritato et al. 1992; Miller 1992). Kay and Thomas (1993) claim that the concentrations of thermophilic actinomycetes in litter and air constitute a human health hazard for workers performing litter operations. These results concord with our observations.

Given the unresolved risks associated with thermophilic actinomycetes and *A. fumigatus*, Lacey et al. (1982) recommend that workers in this environment wear HEPA-equipped (High Efficiency Particulate Air Filters) masks capable of capturing 99.7% of spores. These masks should be stored in a clean, dry, and dark place when not in use, to prevent the growth of microorganisms in the filters (AIHA 1989; Pasanen et al. 1993).

CONCLUSIONS

This study measured the chemical and biological contaminants present in the air of a grower-finisher pig building using the deep-litter method and assessed the safety of these workplaces for workers.

Chemical contaminants never exceeded 50% of their exposure limit, regardless of season. The highest average concentrations of total and Gram-negative bacteria were found in the winter and were 27 and 4 times higher than the limits recommended in waste-treatment and composting facilities. The bacterial concentrations appear to be comparable to those associated with conventional pig-housing facilities in Québec. The concentration of Gram-negative bacteria in the summer was below recommended limits. The highest average concentration of thermophilic actinomycetes was 8.7×10^3 ($\pm 3.5 \times 10^3$) CFU/m^3, while that of *Aspergillus fumigatus* was 9.4×10^3 ($\pm 5.4 \times 10^3$) CFU/m^3; both these values were recorded during the summer sampling series. The average litter temperature was similar to those reported by other authors and ensures an environment which is hospitable to thermotolerant microorganisms. Molds were present at concentrations of 3.5×10^3 ($\pm 4.3 \times 10^2$) to 8.7×10^3 ($\pm 3.5 \times 10^3$) CFU/m^3, with the highest concentration measured in summer. In the winter, when outdoor concentrations of mould were essentially zero, the average concentration after litter stirring was 6.3×10^3 ($\pm 1.9 \times 10^3$) CFU/m^3. Concentrations of this magnitude are common in pig-housing facilities.

Given the unresolved risks associated with thermophilic actinomycetes and *A. fumigatus*, it is recommended that workers in this environment wear HEPA-equipped (High Efficiency Particulate Air Filters) masks capable of capturing 97% of spores.

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