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Odour emissions from livestock production facilities

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Odour emissions from agricultural enterprises are the cause of many complaints from neighbours. A project, funded by the Emilia-Romagna Region, was aimed to assess the importance of the different livestock categories in odour emissions and the effectiveness of some reducing techniques. The project took into consideration the main animal categories: dairy cattle, fattening pigs, laying hens and broilers, and some mitigating techniques for reducing odour (and ammonia) emissions from animal houses and manure storage facilities. Odour emissions were measured by dynamic olfactometry in compliance with European Standard EN 13725. The measurement campaigns covered the different seasonal periods of the year as both odour emissions and the ventilation rate of the stall were greatly influenced by temperature. Odour samples were collected at different times of the day so as to include both animal resting and activity conditions. The results showed higher odour emissions in traditional houses than in renovated buildings: the BATs (Best Available Techniques) managed to reduce odour emissions by 25% to 60%. Odour emission rates varied considerably throughout the day and the year, with higher odour concentration in winter, when the exhaust air flow rate is lower, and lower odour concentration, but usually higher odour emissions, in summer. The highest emissions per unit of animal live weight were from laying hens, followed by broilers, pigs and cattle in this order. Pigs had instead the highest average odour concentration of exhaust air, while it was very low for dairy cows.

1. Introduction

The aim of the study was the investigation of odour emissions from livestock facilities, an activity often involved in odour complaints (Valli, 2001), and the evaluation of the efficiency in reducing odours of a number of mitigating techniques, in particular those considered Best Available Techniques (BATs) by the IPPC Directive (BREF, 2002).

2. Materials and Methods

The odour concentration measurements were made by dynamic olfactometry at the C.R.PA. olfactometric laboratory, in compliance with the EN 13725 standard. As far as animal houses were concerned, the air flow rate was also measured in order to assess odour emission rates as a product of the odour concentration and the ventilation rate.

2.1 Animal houses

As far as animal **houses** were concerned, measurements were made on 3 types of cattle houses, 4 types of pig houses, 3 types of laying hens houses and 2 types of broiler houses.

The types of ***cattle*** houses taken into consideration were:
- conventional tie-stall;
- loose house with deep litter;
- loose house with cubicles.

The types of ***pig*** houses taken into consideration were:
- fully slatted floor with overflow manure pit underneath;
- partially slatted floor with overflow manure pit underneath;
- fully slatted floor with a fast slurry removal system called 'Vacuum System';
- fully slatted floor with a fast slurry removal system with flush tubes, called 'Lusetti system',

The types of ***laying hen*** houses taken into consideration were three battery systems with different manure management systems, resulting in different emission levels. One of them is unanimously known as BAT throughout Europe, while the other one is considered a BAT only in warm European countries. The techniques monitored were:
- *stair-step battery* system with prolonged manure storage underneath;
- *deep-pit house* with ventilated and prolonged manure storage on the ground floor and layer cages on the first floor;
- vertical tier battery with *ventilated manure belt* underneath and frequent droppings removal;

As far as ***broilers*** are concerned, since houses with modern technological equipment are quite similar, two typical houses currently used in Romagna region were taken into consideration. Both used fully littered housing systems with chopped straw bedding, but they had different technological equipment. The former was equipped with modern feeding and drinking systems (nipple drinkers with drip water catch bowls) as well as a computerised climate control system (ventilation, heating), whereas the latter was provided with bell drinkers and relied on less sophisticated ventilation and heating systems (on/off and manual).

In every type of housing facility, measurements were made at the exhaust outlet of the air exchange fans or, if there was natural ventilation, at air outlets.

Measurements were made under the two opposite seasonal conditions in order to assess the impact of environmental conditions on emission levels. At least 20 measurements at different times of the day were taken for every type of stall. Samples were collected with a vacuum sampler directly at the outlet of exhaust fans.

2.2 Manure storage

As far as the measurements of manure **storage** emissions were concerned, batch reactors conceived for this very purpose were used for cattle and pig slurry in order to ensure controlled sampling conditions. Odours were sampled and subsequently measured by dynamic olfactometry, while ammonia and other gas emissions were directly measured by a photoacustic detector. These reactors were also employed to evaluate the effectiveness of some types of simplified floating covers (maize stalks, wooden chips, vegetable oil, expanded clay, wheat straw) in reducing emissions (Guarino et al., 2006). Each floating cover was tested at a thickness of 70 and 140 mm if solid, while 3 mm and 9 mm thicknesses were chosen for the liquid cover (vegetable oil). In order to carry out accurate and repeatable measurements and to simulate the average storage conditions of farm tanks, nine stain steel airtight cylinders with a volume of 190 dm^3 were used and each of them was partially filled with about 60 dm^3 of slurry. For each covering system nine batch reactors were used: three of them were set up with the 1st covering thickness, three other reactors with the 2nd covering thickness and the last three batch reactors were set up without any covering as a reference. To determine the efficiency of the covers tested in odour abatement, one air sample was taken from each reactor and submitted to olfactometric analysis. Before sampling, the headspace was blown by an airflow of 6 L min^{-1} for 15 min to obtain a sufficient exchange of air by means of one diffusion disk whose diameter was slightly smaller than the one of the reactor (***Figure 1a***). Afterwards, about 8 dm^3 of odorous air from the headspace were collected in nalophan bags. Odour samples were taken by means of a sampling probe placed into the reactor about 0.02 m from the slurry surface (either covered or not). A pump connected with a charcoal filter allowed blowing purified air on the surface of the slurry: odorous air coming from the headspace was then collected into nalophan bags and analysed with the olfactometric technique (C.E.N., 2003).

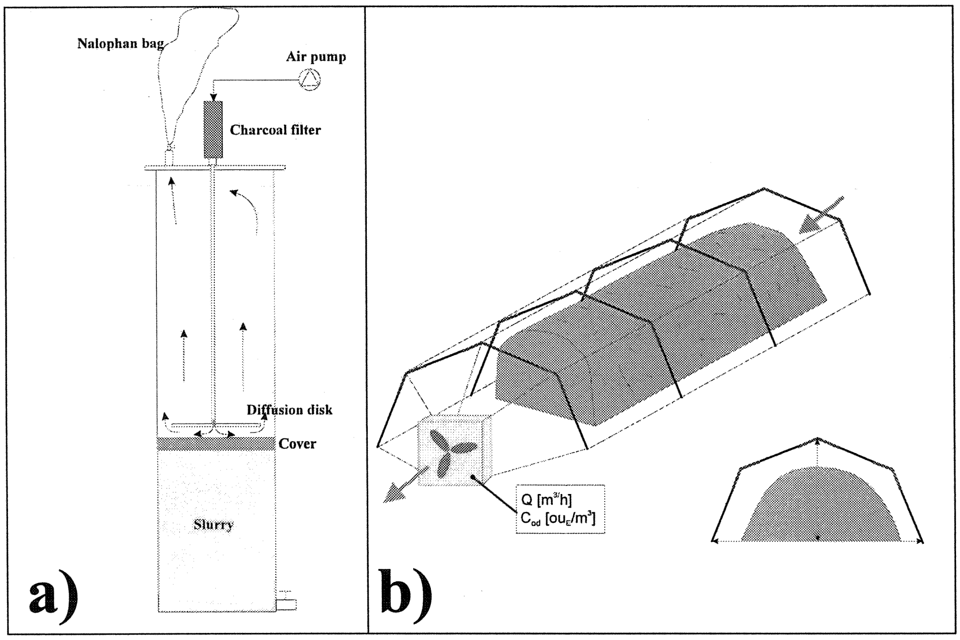

Figure 1 – The equipments used for odour measurements from slurry and manure storage: a) the cylinder for odour emission measurement from slurry storage; b) the wind tunnel for odour emission measurement from manure heaps.

As regards emissions from solid manure storage, like laying hen droppings and broiler litters, special sampling equipment was set up (***Figure 1b***). This equipment was made up of a large 'wind tunnel' (3x6m base x 2.5m height) which could host a significant volume of manure, enough to develop and sustain the organic matter degradation processes that usually develop in full-scale heaps. Measurements were made on two broiler litter heaps and two heaps of laying hen manure, which had different dry matter contents (Total Solids =TS) when the heap was prepared (respectively TS = 55% and 70% for broiler litter and TS% = 45% and 65% for laying hen manure). The heaps were stored for about 3 months.

3. Results

3.1 Animal houses

The odour concentration, measured by dynamic olfactometry, are expressed in $ou_E\ m^{-3}$, in compliance with EN 13725[1]. The results of animal house measurements are expressed as odour emission referred per animal live weight (lw) unit ($ou_E\ s^{-1}\ t_{lw}^{-1}$).

Dairy cows

Odour concentration in dairy cow houses ranged from 9 to 163 $ou_E\ m^{-3}$. The emissions, determined on the basis of a mean ventilation estimate per unit of live weight (lw), ranged between 11 and 101 $ou_E\ s^{-1}\ t_{lw}^{-1}$ (***Table 1***). No significant differences were found between the types of dairy cow houses monitored. It must be noted that in these three facilities, like in virtually all dairy cattle houses, ventilation was natural and this made it more difficult to collect representative samples of extract air and, what is more, made ventilation rate measurement very uncertain.

Table 1 – Odour emissions from dairy cattle houses.

Animal category	Housing system	**Odour emissions** ($ou_E\ s^{-1}\ t_{lw}^{-1}$)					
		mean	min	max	Std. dev.	CV	No. of data
Dairy cows	Tied cows	**22**	11	36	7	0.32	20
	Cubicles	**30**	11	82	19	0.64	20
	Deep litter	**32**	10	101	22	0.68	20

Fattening pigs

Odour concentration in fattening pig houses ranged from 62 to 2500 $ou_E\ m^{-3}$, with average values that were higher in winter because of the lower winter ventilation rates, resulting in concentrating odorous compounds. In general, winter odour concentration values were more than twice summer values. Higher average values were found in the fully slatted floor facility with overflow manure pit underneath (896 $ou_E\ m^{-3}$). Odour concentration were slightly lower in the partially slatted floor house with overflow manure pit underneath (620 $ou_E\ m^{-3}$), while the fully slatted floor facility with a fast slurry removal system called ‘Vacuum System’ had similar values (474 $ou_E\ m^{-3}$). The lowest odour concentration (300 $ou_E\ m^{-3}$) was noted in the fully slatted floor house with a fast slurry removal system with flush tubes (Lusetti System).

Differences in odour emissions were much more limited (***Table 2***) as they ranged from 33 $ou_E\ s^{-1}\ t_{lw}^{-1}$ to 247 $ou_E\ s^{-1}\ t_{lw}^{-1}$. As a matter of fact, emissions result from the product

[1] ou_E = European Odour unit (as defined by the EN 13725). It is the unit of measurement for odour concentration. 1 ou_E corresponds to the amount of odorants which diluted in one cubic metre of neutral air produces a barely perceptible olfactory physiological response (1 ou_E/m^3 is the odour concentration corresponding to the olfactory threshold).

of odour concentration (low levels in summer and high levels in winter) by the flow rate of exhaust air (high levels in summer and low levels in winter).

Table 2 – Odour emissions from fattening pig houses.

Animal category	Housing system	**Odour emissions** (ou_E s^{-1} t_{lw} $^{-1}$)					
		mean	min	max	Std. dev.	CV	No. of data
Fattening pigs	FSF LS	**52**	33	105	19	0.36	23
	FSF VS	**102**	44	132	27	0.26	26
	FSF OP	**142**	90	247	43	0.30	30
	PSF OP	**98**	40	195	38	0.38	30

Notes: lw = live weight; FSF = fully slatted floor; PSF = partially slatted floor; OP = overflow pit; VS = vacuum system; LS = Lusetti System.

The housing type with the lowest emission levels was the fully slatted floor solution with a fast slurry removal system with flush tubes (Lusetti system) since its mean level was 52 ou_E s^{-1} t_{lw} $^{-1}$, whereas the 'reference' system (fully slatted floor facility with overflow manure pit underneath) had the highest emission levels (142 ou_E s^{-1} t_{lw} $^{-1}$). The partially slatted floor facilities (98 ou_E s^{-1} t_{lw} $^{-1}$) and the Vacuum system (102 ou_E s^{-1} t_{lw} $^{-1}$) were at an intermediate level. The reduction rate that could be achieved over the reference system with the LS technique equalled 63%, while the reduction rate with both the partially slatted system and the VS system was about 30%. It must however be noted that the fast slurry removal technique resulted in very strong odour emissions precisely when recirculation was operated. Concentrations during this critical operation ranged between 1000 and 4500 ouE m-3. However, this operation was of short duration and took place twice a day only.

Laying hens

Odour concentration values in laying hen houses ranged from 20 and 2500 ou_E m^{-3}, with higher values for the traditional stair-step battery with prolonged manure storage underneath (641 ou_E m^{-3}), while lower average values were noted both in the battery system with ventilated manure belt (233 ou_E m^{-3}) and, more markedly, in the deep-pit house (143 ou_E m^{-3}).

The analyses of odour emissions per unit of live weight (***Table 3***) showed that the two systems based on manure drying in the houses (ventilated belt and deep-pit systems) had virtually similar values (145 ou_E s^{-1} t_{lw} $^{-1}$ for deep-pit houses and 158 ou_E s^{-1} t_{lw} $^{-1}$ for ventilated belt systems), whereas much higher values, about twice as much (360 ou_E s^{-1} t_{lw} $^{-1}$) were found in traditional stair-step batteries with prolonged manure storage underneath.

Table 3 – Odour emissions from laying hen houses.

Animal category	Housing system	**Odour emissions** (ou_E s^{-1} t_{lw} $^{-1}$)					
		mean	min	max	Std dev.	CV	No. of data
Laying hens	Stair-step cages	**361**	142	1335	372	1.03	20
	Deep-pit	**145**	24	258	75	0.52	30
	Ventilated belt	**158**	30	444	120	0.76	30

Broilers
Odour concentration values in broiler houses ranged from 48 and 1069 ou_E m^{-3}, with an average value of 221 ou_E m^{-3} for computerised climate control housing and 329 ou_E m^{-3} for manual climate control housing. Even by taking into account the emissions per unit of live weight (***Table 4***), the results show the same trends, although differences between housing systems are less marked because of the lower ventilation rates of climate control housing controlled by an on/off system. Mean emissions for automated control housing were 126 ou_E s^{-1} t_{lw}^{-1}, while mean emissions for manual control housing were 152 ou_E s^{-1} t_{lw}^{-1}.

Table 4 – Odour emissions from broiler houses.

Animal category	Housing system	**Odour emissions** (ou_E s^{-1} t_{lw}^{-1})					
		mean	min	max	Std. dev.	CV	No. of data
Broilers	Automatic control	**126**	43	276	60	0.48	30
	Manual control	**152**	50	330	75	0.49	25

3.2 Manure storage

Odour concentration in the air sampled from batch slurry storage was on average 3400 ou_E m^{-3} for cattle manure and 2800 ou_E m^{-3} for pig manure. Their emissions per unit of surface equalled 2.72 ou_E $m^{-2}s^{-1}$ for cattle manure and 2.24 ou_E $m^{-2}s^{-1}$ for pig manure (***Table 5***). Odour emissions from both cattle and pig slurry were higher in summer than in winter (3.62 ou_E $m^{-2}s^{-1}$ versus 1.82 ou_E $m^{-2}s^{-1}$ for cattle slurry and 2.96 ou_E $m^{-2}s^{-1}$ versus 1.51 ou_E $m^{-2}s^{-1}$ for pig slurry), showing a 100% increase in emissions in both cases.

Table 5 –Odour emissions from cattle and pig storage.

Type of slurry	Season	**Odour emissions**		
		mean [ou_E $m^{-2}s^{-1}$]	Std dev. [ou_E $m^{-2}s^{-1}$]	CV
Cattle slurry	Summer average	3.62	1.69	0.47
	Winter average	1.82	0.86	0.47
	Yearly average	**2.72**	1.60	0.59
Pig slurry	Summer average	2.96	0.95	0.32
	Winter average	1.51	0.47	0.31
	Yearly average	**2.24**	1.04	0.47

As far as the effectiveness of the different floating covers made of low-cost materials tested on slurry storage was concerned, all the materials proved to be very effective in reducing odours from **pig slurry** (***Figure 2a***) when used with higher thickness; in particular, with reference to maize stalks, odour reduction could be as much as 90%. Good efficiency levels in odour emission reduction were also found with lower thicknesses for all the main materials, except for wheat straw. Its atypical value is probably due to its tendency to sink in slurry with a low dry matter content, like pig slurry. In the trial carried out with **cattle slurry** (***Figure 2b***), the negative result shown by wooden chips may be due to particular reactions of the wood with the slurry which might have produced additional odour, thus increasing the odour concentration of the samples.

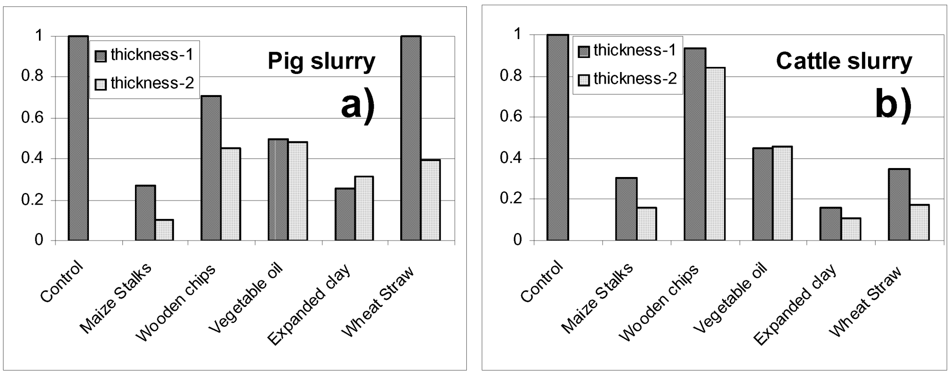

Figure 2 – Odour emissions from slurry storage covered with different floating covers, versus uncovered slurry (assumed equal to 1). ***a****: cattle slurry;* ***b****: pig slurry.*

As far as measurements of poultry manure storage heaps were concerned, odour concentration, as well as emissions, were significantly higher in the litter heap with a higher moisture content and summer values were substantially higher than in winter cycles (200 versus 30 ou_E s^{-1} t_{manure}^{-1} for wetter litter and 80 versus 17 ou_E s^{-1} t_{manure}^{-1} for drier litter). As a matter of fact, low environmental temperatures affect also heap temperature, slowing down the degradation processes odour emissions result from. In addition, odour gradually diminished in both heaps over time as the stabilisation process of the organic matter developed (***Figure 3a***).

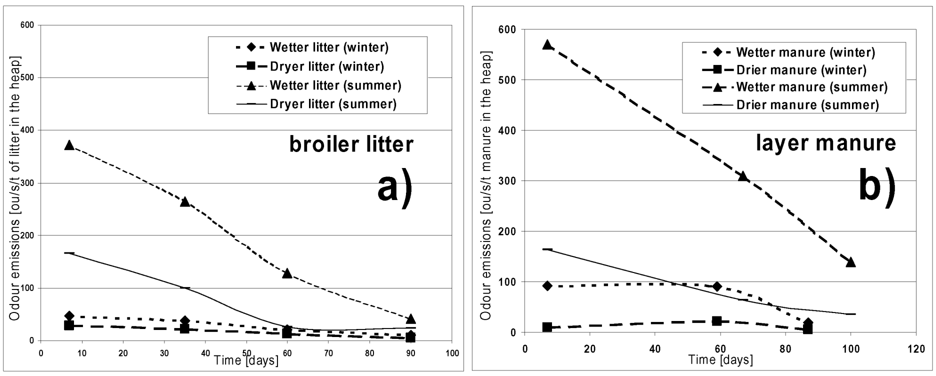

Figure 3 – Odour emissions from poultry manure storage heaps throughout 3 months of storage. ***a****: broiler litter;* ***b****: laying hens droppings*

Remarks similar to those on litter apply to laying hen manure storage. As a matter of fact, odour concentration and emissions were higher for low dry-content manure and substantially higher for the summer cycle than for the winter cycle (340 versus 70 $ou_E\ s^{-1}\ t_{manure}^{-1}$ for wet manure and 90 versus 12 $ou_E\ s^{-1}\ t_{manure}^{-1}$ for drier manure). In general, odour diminished over time (***Figure 3b***), except for the first samples of the winter cycle, for which it can be assumed that low temperatures delayed the beginning of the aerobic degradation processes of the organic matter.

4. Conclusions

The project carried out allowed the identification of the characteristics of odour emissions from one of the enterprises with the highest impact in terms of olfactory nuisance, i.e. animal housing (cattle, pigs and poultry).

The highest missions per animal live weight unit were from laying hens, followed by broilers, pigs and cattle, in this order. Pigs had instead the highest mean odour concentration of exhaust air, while it was very low for dairy cows.

The activity carried out to evaluate the effectiveness of some emission reducing techniques in pig and poultry housing led to the conclusion that the techniques considered as BATs were effective also in reducing odorous emissions. As a matter of fact, pig housing systems with fast manure removal techniques entailed a reduction in emissions by 30 to 60%, while laying egg housing facilities based on fast manure drying techniques allowed reducing odour emissions by about 60%. Finally, broiler housing facilities with automatic control air-conditioning systems reduced emissions on average by about 16% manual control systems.

4. Acknowledgements

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3. References

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