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Odour and ammonia emissions from cattle slurry treated with anaerobic digestion

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An experiment was set-up in order to assess the difference in odour and ammonia emissions from three types of cattle slurry: two coming from farms with different types of housing systems and one from a farm with an anaerobic digestion plant. The aim was to assess whether the anaerobic digestion process, besides its unquestionable energy benefits, is effective in reducing odour and other gases emissions of the effluent at the end of the treatment, the so-called digestate.
The tests were carried out in laboratory conditions, simulating storage conditions similar to those in the farm storage tanks. Measurements were taken on eight sampling occasions with four replicates per each slurry type.
Results show that the odour emissions from the digested slurry are greatly reduced in comparison with both the undigested slurries, but, on the contrary, ammonia emissions are increased.

1. Introduction

The new legislation providing incentives for the production of energy by means of renewable sources has been a driving force in the spread of anaerobic digestion plant in livestock farms, particularly those with cattle.
Among the benefits to be derived from the application of anaerobic digestion techniques to livestock effluent, in addition to those of an economic/energy nature, are those of an environmental character such as reduction in greenhouse gases emissions. This is achieved both directly in the capture and re-use of the bio-gas produced as energy and indirectly, with the replacement of fossil fuels with fuels from renewable sources. A further advantage is that of a significant reduction in both odour levels and the emission of other organic compounds deriving from the storage of the slurry at the end of the treatment in the form of so-called digestate.
The emission of ammonia and odours by the slurry contained in the storage tanks depends on various factors: the concentration of ammonia nitrogen, ph, the temperature of the slurry, of the air and the environment, total solid content and the physical characteristics of the upper layer of the slurry exposed to the air. The anaerobic digestion of cattle slurry in biogas production plant, particularly when nitrogen-rich vegetable or animal biomass is added, gives rise to significant variations in these parameters. In particular, anaerobic digestion results in the degradation of complex molecules to simpler organic compounds: proteins are degraded and the nitrogen present is mineralised in ammoniacal forms. The main consequence of this

transformation is a potential increase of ammonia emissions. The degradation of volatile organic compounds to carbon dioxide and methane however, should, on the contrary, result in a reduction of odour emissions.
To assess whether the emissions of gases and odours from the storage of slurry leaving the anaerobic digestion plant were actually reduced and if so, the extent of such reductions with respect to non-digested slurry, CRPA carried out a number of laboratory tests within a project on the anaerobic digestion of cattle slurry, funded by the Region of Emilia-Romagna.

2. Materials and Methods

The research was set up to compare odour and ammonia emissions from three types of cattle slurry: two coming from farms with different types of housing systems and one from a farm with an anaerobic digestion plant:

- **Slurry 1 (Control = CO)**: slurry coming from a farm using cubicles with mattress, with slurry storage in uncovered tank without anaerobic digestion. This slurry, taken from the storage tank, is characterised by absence of straw and by relatively low ammonia nitrogen content. It does not tend to form a surface crust during storage;
- **Slurry 2 (Digested = DI), slurry subjected to anaerobic digestion** originating from a farm with cubicles with mattress with anaerobic digestion and subsequent storage in tank. This slurry, taken from the storage tank downstream of the digester, is characterised by a high level of ammonia nitrogen, the absence of straw but with tendency to form a slight surface crust due to the addition of vegetable biomass during the anaerobic digestion process;
- **Slurry 3 (Crusted = CR):** slurry originating from a farm using cubicles with straw and with slurry storage in uncovered tank without anaerobic digestion. This is a fresh slurry taken from the feeding passage-way characterised by a relatively low ammonia nitrogen content with high levels of volatile solids, the presence of straw and the tendency to form a **surface crust in the storage tank**. It was not possible to take this slurry directly from the storage tank because of the formation of a thick surface layer preventing the collection of a sufficiently representative sample.

Measurements were taken on eight occasions when the following parameters were established:

- analytical characteristics of the slurry (pH, total nitrogen, ammoniacal nitrogen, total solids and volatile solids);
- odour emissions;
- ammonia emission.

In order to create laboratory conditions similar to those in the farm storage tanks over the four days prior to the measurement the different types of slurry were stored inside reactors with a volume of 3 litres and placed in a thermo-ventilated chamber at 20° C to encourage the formation of a surface crust or skin and to mimic the environmental conditions. Four replications were taken from each slurry type sample for each measurement session, thus a total of 32 samples were tested for each slurry type.

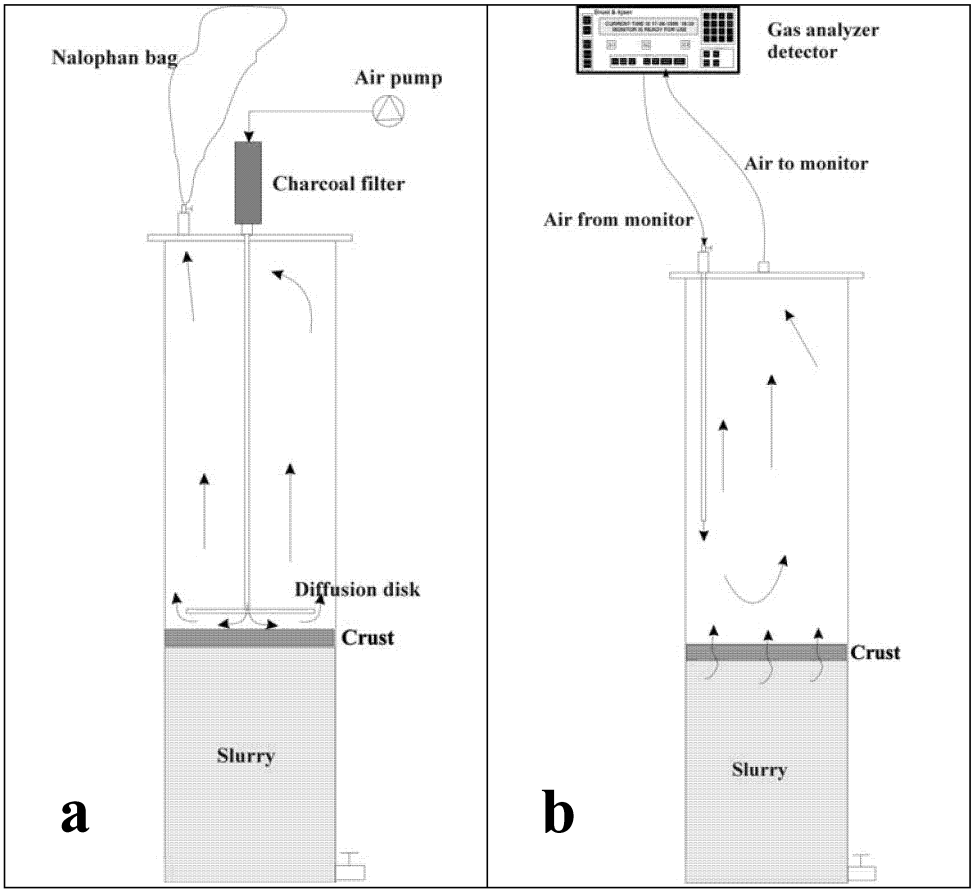

Figure 1. *Device used for the measurement of the slurry emission potential: the sampling of the odour bags for the odour concentration measurements (a) and the on-line measurement of the gas saturation curve (b)*

A special device was used for the measurement of the odour emissions from the slurry (*Figure 1a*). The device was used to take an air sample by skimming the surface of the slurry contained in the reactors at a pre-set speed. The sample was then analysed by dynamic olfactometry at the CRPA olfactometric laboratory, following the procedures described by the European Standard *EN 13725*. The same reactors used for odour emissions were also used for the measurement of potential ammonia emissions. The gas emissions were evaluated using the "saturation chamber" method, involving the analysis of the variation in gas concentrations within a hermetically sealed chamber in such a way as to eliminate all gas exchanges with the external environment (*Figure 1b*). The concentration of gas compounds increases in the head space of this chamber in accordance with a growth curve which is initially in a straight line and then flattens out as the compound saturation point becomes closer. By measuring the slope of the

straight line at the initial phase it is possible to calculate the emission of the gaseous compound over the unit of time and surface area.
Physical/chemical analyses were carried out on slurry stored inside the reactors after the measurement of emissions and after the sampling of the air for the olfactometric tests. Samples were taken of the layer of about 5cm immediately underneath the surface crust or skin. The final slurry sample for each type was obtained by mixing the sub-samples of the four replications from each measurement session.

3. Results and discussion

The analytical characteristics of the slurry tested for emissions have been summarised in *Table 1* with an indication of the average values and the standard deviation of the eight measurement sessions effected. It can be noticed the higher dry matter content (TS = 13%) of the slurry 3 (crusted slurry), wich is rich in straw, in comparison with the slurry 1 (control), whose TS just reached 4%. Volatile Solids too are highest in the slurry 3, which is fresh slurry. The highest level of ammoniacal nitrogen concentration (1824 mg/kg) and pH (8.47) were measured in the digested slurry.

Table 1. Chemical-physical composition of the three different types of slurry (standard deviation in brackets)

Parameter	Unit	**Slurry 1**		**Slurry 2**		**Slurry 3**	
		Control		*Digested slurry*		*Crusted slurry*	
Total Solids (TS)	(g/kg)	44.53	(22.31)	84.90	(40.39)	127.61	(23.67)
	(%)	*4.45*	*(2.23)*	*8.49*	*(4.04)*	*12.76*	*(2.37)*
Volatile Solids (VS)	(g/kg)	29.05	(16.42)	60.48	(32.65)	102.53	(18.28)
	(%TS)	*62.99*	*(6.94)*	*69.54*	*(4.77)*	*80.43*	*(2.22)*
Total Nitrogen (TKN)	(mg/kg)	2528	(1083)	4535	(1248)	3689	(766)
	(%TS)	*5.95*	*(1.09)*	*5.76*	*(1.10)*	*2.92*	*(0.48)*
Ammoniacal nitrogen ($N\text{-}NH_4^+$)	(mg/kg)	992	(195)	1824	(177)	1137	(321)
	(%TKN)	*42.44*	*(9.13)*	*42.97*	*(12.24)*	*30.93*	*(7.64)*
pH	(-)	7.82	(0.30)	8.47	(0.17)	8.28	(0.38)

Emission of odorous compounds
The odour concentration data measured in the air fluxed over the surface of the slurry inside the laboratory reactors have been set out in *Table 2* and shown in *Figure 3*. the values are the average of the eight measurement sessions, each of which consisting in four replications per type. Standar deviation (sd) and coefficient of variation (c.v.) are also reported.

Table 2: Average odour concentration for each type of slurry (measured in ou_E/m^3 in compliance with the EN 13725[1])

Sample	Odour Concentration				
	mean	sd	c.v. %	Difference as compared with control	Signif.
	($ou_E\ m^{-3}$)	($ou_E\ m^{-3}$)	(%)	(%)	
Slurry1 (CO)	197	120	61%		
Slurry2 (DI)	71	39	55%	-64%	***
Slurry3 (CR)	256	157	62%	+30%	n.s.

Student t test: n.s. not significative difference; * P<0.05; ** P<0.01; *** P<0.001

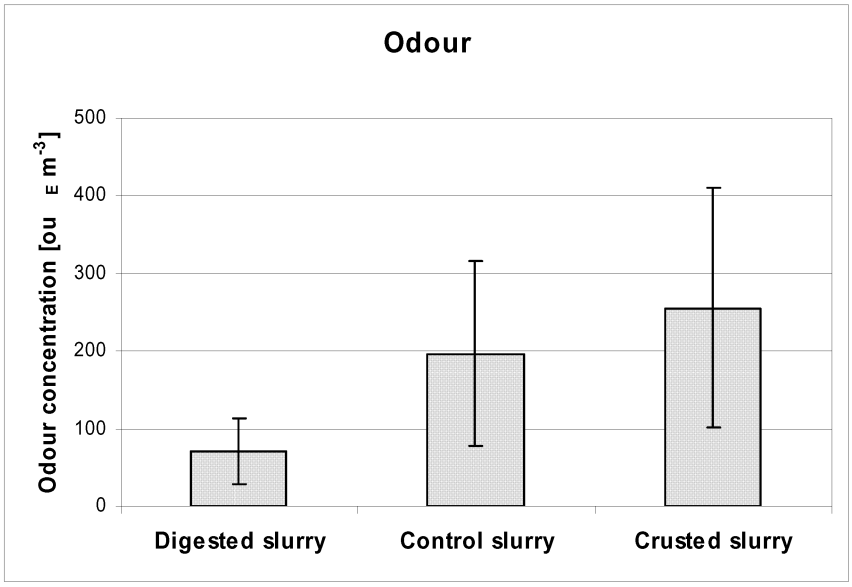

Figure 3: *Odour concentrations in the different measurement sessions for each slurry type.*

It can be seen that the odour concentration in the air extracted from the DI reactor sample is significantly less both than the CO and the CR samples. This result

[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).

emphasises the fact that the degradation of the organic compounds during the anaerobic digestion process leads to a significant reduction in the odour emissions of the digested slurry. The average odour emissions for this sample was less than 64% of that of the control sample (*Table 2*). Reduced odour emissions from anaerobically digested slurry has also been described by a number of international studies (Hansen et al., 2006; Powers et al., 1999; Pain et al., 1990).
Measurements for the CR sample recorded odour emissions on average more than 30% of those of CO even though this difference is not significant for the statistical analysis. The unsatisfactory results in relation to the reduction of odour emissions from the surface crust may be explained on the one hand by the fact that fresh slurry was used for the CR sample because of the sampling difficulties explained above, hence with a percentage of volatile solids which is higher than that of the other two samples, and, on the other, by the fact that the crust forming in this laboratory test in small diameter containers was much less dry and compact than that which is likely to form in real conditions.

Ammonia Emissions
Table 3 sets out ammonia emission data, expressed as an average of the eight measurement sessions (four replications per session for each of the three samples considered). Standar deviation (sd) and coefficient of variation (c.v.) are also reported.

Table 3: Summary of ammonia emissions from laboratory reactors in the different samples.

Sample	**Ammonia emissions**				
	mean	sd	c.v.	Difference as compared with control	Signif.
	(mg $NH_3m^{-2}.h^{-1}$)	(mg $NH_3m^{-2}.h^{-1}$)	(%)	(%)	
Slurry1 (CO)	121	26	22%		
Slurry2 (DI)	208	47	22%	+ 73%	***
Slurry3 (CR)	88	47	53%	- 27%	***

Student t test: n.s. not significative difference; * P<0.05; ** P<0.01; *** P<0.001

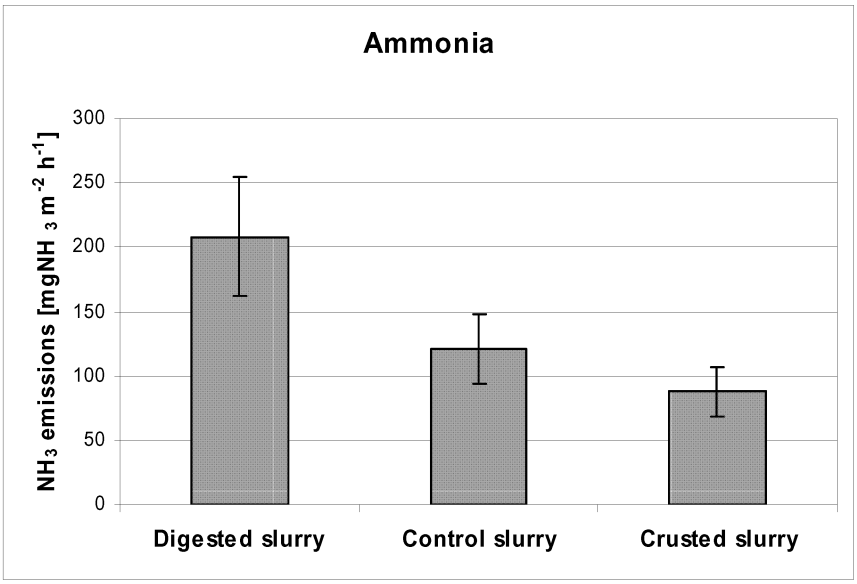

Figure 4. *Ammonia emissions for each slurry type.*

The emission of ammonia from slurry resulting from anaerobic digestion (*Figure 4*) is significantly higher both than the CO (untreated slurry) and than the slurry from the CR sample (slurry with crust) in all measurements carried out over all tests. These measurements are compatible with the chemical characteristics of the material coming from anaerobic digestion, presenting on average, a greater concentration of ammonia nitrogen (double with respect to the control sample and almost double that of the CR sample) with greater basicity as compared with the slurry of the other two samples, factors tending to favour increased ammonia emissions. Similar increase in the NH_3 emissions from uncovered anaerobically digested slurry due to the high NH_4-N content and pH value are reported by Amon et al. (2004). The formation of a superficial crust on the CR sample reduced ammonia emissions to an extent that was statistically significant (average reduction = 27%) with respect to the control notwithstanding the fact that ammonia concentrations were the same. The reduction was less than recent results reported in the literature (Smith et al. 2007) where reductions in ammonia emissions from storage of cattle slurry with a surface crust are described as typically in the order of 60%. Those tests were however carried out using pilot containers whose size reflected real conditions in which much more complete crust formation is achieved as compared with the laboratory situation where our own tests were conducted.

4. Conclusions

The tests carried out confirmed that the effluent downstream of the anaerobic digestion of livestock slurry, the so-called digestate, presents gas and odour emissions which are

different from untreated slurry. In particular, comparisons were made with untreated slurry with very little straw-like matter and hence, physically, fairly similar to the digestate and with untreated slurry containing a high level of straw-like material – thus characterised by a higher level of dry matter and the tendency to form a surface crust during storage.

Odour emissions from the cattle digestate was significantly reduced as compared with the slurry incorporating both low and high levels of straw-like material. On the other hand, the ammonia emissions of the digestate were significantly higher both than the untreated slurry with little straw and, to an even greater degree, the slurry with higher straw content. In this latter case indeed, the straw encourages the formation of a surface crust acting as a cover for the surface gas exchanges and hence reducing ammonia emissions. The higher ammonia emissions by the digestate can be explained by reference to the chemical characteristics of the material coming from the anaerobic digestion, presenting as it does on average, a higher concentration of ammonia nitrogen and greater basicity as compared to untreated slurry.

The reduction in odour offensiveness of the digested slurry, an additional benefit reported in a number of international studies, is fully confirmed in our experiment. Neverthless the reduction of ammonia and greenhouse gases could only be aceived if the storage of the digestate is effected, at least in part, in a tank covered by the gasometric dome for the storage of the biogas. Plant configuration of this type permits a further recovery of residual biogas, thus removing a part of the emissions that would otherwise be discharged directly into the atmosphere.

3. Acknowledgements

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