RESEARCH

The effect of floating covers on gas emissions from liquid pig manure

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Livestock manure is the source of different pollutant gases that can generate soil acidification, eutrophication, and contribute to global warming, or have a negative impact on health. Covers can control gas emissions from manure, but their impact is still under discussion. The aim of this experiment was to study the effect of different covers on methane (CH_4), nitric oxide (NO), hydrogen sulfide (H_2S), ammonia (NH_3), carbon monoxide (CO), and carbon dioxide (CO_2) emissions from liquid pig manure. Six types of floating covers were tested: light expanded clay aggregate (leca), peat, sunflower oil, sawdust, straw, and plastic film. Manure was stored at 5, 15, and 25 °C for 37 d. Gas emissions were measured from the headspaces of the dynamic chambers. The results of our study showed that both cover and temperature have a noticeable impact on gas emissions from liquid pig manure. The plastic film cover was the most efficient at all tested temperatures because it reduced emissions of all the measured gases. In this case, mean emission reductions were: CH_4 91.5% ($P < 0.01$), NO 92.0% ($P < 0.05$), H_2S 78.1% ($P < 0.05$), NH_3 54.7% ($P < 0.01$), CO 98.4% ($P < 0.01$), and CO_2 67.1% ($P < 0.01$). Other covers had an inconsistent impact on separate gas emissions. However, covers generally helped to decrease NH_3, H_2S, and CO_2 emissions.

Key words: Emission reduction, livestock excreta, pig manure, pollutant gases.

INTRODUCTION

Large quantities of different pollutant gases can be emitted during animal manure storage. Livestock manure is the emission source of such gases as ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2), hydrogen sulfide (H_2S), carbon monoxide (CO), and nitric oxide (NO). It was estimated that livestock excreta accounts for more than 80% of NH_3 emissions from European agriculture, and it contributes 5% of total CH_4 emissions (EEA, 2009; Sommer et al., 2009). The emission of NH_3 and CH_4 can cause serious environmental problems and/or health risks. The emission of NH_3 leads to soil acidification and eutrophication (European Commission, 2011). Similar to CO_2, methane contributes to global warming (IPCC, 2006). Both NH_3 and H_2S have a negative impact on health. Likewise, CO and NO can have an adverse effect on human health. Nitric oxide is also involved in the formation of ozone (EEA, 2009). Measures should therefore be taken to control gas emissions from manure and minimize or eliminate the negative impact on the environment.

A variety of options exist for mitigating gas emissions from manure. However, methods differ in effectiveness, cost, practicality, and expertise required to operate them efficiently. Good results were obtained with covers, at least to reduce NH_3 emissions (Brink et al., 2005; Webb et al., 2006; Ndegwa et al., 2008; VanderZaag et al., 2009). Stationary (a 'tight' lid, roof or tent structure) or floating covers can be used. Stationary covers are much more expensive than floating covers, and it is difficult to install them on large stores (Webb et al., 2006). There is a range of floating covers that could reduce NH_3 emission from stored slurries. The impact of covers on the emission of gases other than NH_3 is still under discussion. The study by Bicudo et al. (2004) showed that covers can decrease H_2S emission. Research by Ambus and Petersen (2005), Petersen et al. (2005), Hansen et al. (2006), and Petersen and Ambus (2006) demonstrated that covers can reduce CH_4 emission. However, reduction was not achieved for all types of covers. The study by Petersen and Ambus (2006) showed that a cover of expanded clay product (leca) was not effective to reduce CH_4 emission. Petersen et al. (2009) also noticed that nitrous oxide (N_2O) emission can increase as a consequence of oxidizing processes in the cover. VanderZaag et al. (2009) found that the use of covers might not only increase N_2O emission, but also CO_2. Furthermore, the study by Amon et al. (2006) demonstrated that the type of cover can highly influence emission. The study showed that covering the slurry store with a layer of chopped straw, instead of a wooden cover, increased NH_3 and greenhouse gas (GHG) emissions. Berg et al. (2006) also found increased GHG after using straw and granules as covers. Therefore, the question is whether using covers could help to reduce NH_3 emission,

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but increase the emission of other gases, or if the common effect of covers could be beneficial.

The aim of the current experiment was to investigate the influence of different types of floating covers on CH_4, NO, H_2S, NH_3, CO, and CO_2 emissions from liquid pig manure.

MATERIALS AND METHODS

Experimental design

The current study was carried out at the Lithuanian University of Health Sciences, Institute of Animal Science (Baisogala, Lithuania) under environmentally controlled conditions.

Fresh liquid pig manure was collected from the floor of the pens on the farm of the Institute of Animal Science. Pigs were housed in naturally ventilated buildings with a scraper manure removal system. Pigs were fed concentrates twice a day. The same day manure was transported to the laboratory and homogenized; 72 vessels were immediately filled with 1.0 kg manure each. All the vessels were identical, cylindrical, 110 mm height, 169 mm inner diameter, and with 2.1 L capacity. Half of the vessels were left uncovered, while the rest were covered with a separate floating cover. Covers were applied directly onto the manure surface. Six types of floating covers were tested: light expanded clay aggregate (leca), peat, sunflower oil, softwood sawdust, straw, and black plastic film. Leca was in granular form with a nominal diameter of 10 to 20 mm and low density (250 kg m^{-3}). Sunflower oil was an ordinary food product that is biodegradable, that is, harmless. Wheat straw was chopped to a 6-cm length. The thickness of each cover was as follows: 40 mm leca, 40 mm peat, 40 mm sawdust, 40 mm straw, 2 mm sunflower oil, and 0.1 mm plastic film (for comparisons, the thickness of permeable covers was the same). After all the vessels were filled with homogenized manure and covers were applied, samples were stored in open vessels in three thermostatic rooms and measurements were taken. Covered and uncovered manures were stored under the same conditions. Room temperatures were maintained at 5 ± 1 °C, 15 ± 1 °C, and 25 ± 1 °C. Two replicates were performed for the manure covered with a separate cover and with no cover at each storage temperature. During the experimental period, gas emissions were measured and manure was analyzed for chemical composition. The gas measurement period extended until a tight crust settled on the surface of uncovered manure; the length of the gas measurement period was 37 d (crust acts as a cover, consequently comparing emissions between covered and crusted manure would be counterproductive).

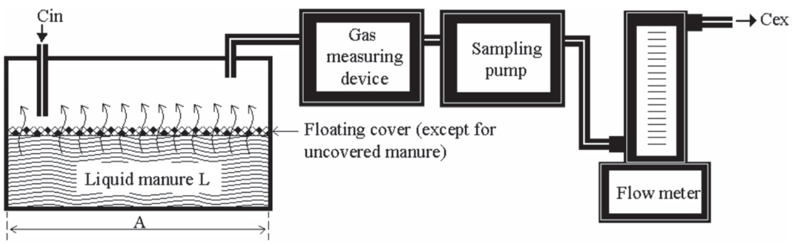
Gas measurement

The dynamic chamber method and gas measuring devices were adopted by using laboratory simulation to analyze gas emissions from the stored manure with a portable multi-gas measuring instrument (Dräger X-am 7000, Dräger Safety AG & Co, Lübeck, Germany) for 0 to 200 ± 1 mL NH_3 m^{-3}, 0 to 100 ± 1 mL NO m^{-3}, 0 to 100 ± 1 mL H_2S m^{-3}, 0 to 44 000 mL CH_4 m^{-3} ± 1%; a multi-gas monitor (M40, Industrial Scientific Corporation, Oakdale, Pennsylvania, USA) for 0 to 999 ± 1 mL CO m^{-3}, 0 to 500 ± 1 mL H_2S m^{-3}, 0 to 50 000 mL CH_4 m^{-3} ± 2%; and a data logger (Almemo 2890-9, Ahlborn Mess und Regelungstechnik GmbH, Holzkirchen, Germany) for 0 to 10 000 mL CO_2 m^{-3} ± 2%. During gas concentration measurements, each vessel was temporally converted into a dynamic chamber by closing it with an airtight lid. The lid had two air inlet and outlet ports as described in the study by Dinuccio et al. (2008). The air outlet port was connected to gas measuring devices, a sampling pump (0.25 L min^{-1}; SP40, Industrial Scientific Corporation), and flow meter (0 to 4 L min^{-1} ± 0.1 mL; RDS-4, Steklopribor, Kiev, Ukraine) (Figure 1). The headspace between the manure surface and the lid was ventilated by pumping air to create a constant 0.015 m^3 h^{-1} air flow rate through the dynamic chamber. Incoming air to the chamber and exhaust air, that leaves each chamber, was sampled and gas concentrations were measured every minute. The mean of the six recorded values was calculated and considered representative of the individual measurement. The vessels were kept open until the next gas measurement; this is similar to the studies by Dinuccio et al. (2008) and Wang et al. (2010). Gas concentrations in each vessel were measured twice a week.

The emission rate of the different gases was quantified using the following Equation [1]:

$$F = Q\,M\,p\,(Cex - Cin)\,R^{-1}\,(T + 273)^{-1}\,A^{-1}, \qquad [1]$$

where F is the gas emission rate (mg m^{-2} h^{-1}) under



Cin: Gas concentration of air inlet into the chamber; Cex: gas concentration of air outlet from the chamber.

Figure 1. Schematic diagram of the gas measuring system.

standard conditions (25 °C and 100 kPa), Q is the air flow rate through the gas measuring system (m^3 h^{-1}), M is gas mole mass (g mol^{-1}), p is gas pressure (kPa), Cin is the gas concentration of the air inlet into the chamber (mL m^{-3}), Cex is the gas concentration of the air outlet from the chamber (mL m^{-3}), R is the gas constant (8.314 J K^{-1} mol^{-1}), T is gas temperature (°C), and A is the surface area of manure (m^2).

Analysis of manure

At the beginning and end of the study, manure samples were taken from each vessel and analyzed for pH, total solids (TS), volatile solids (VS), ash, total Kjeldahl N (TKN), and total ammonia N (TAN). The pH was measured with a pH meter (-2 to 16 ± 0.05; HI 98128, HANNA Instruments, Woonsocket, Rhode Island, USA). Total solids content was determined after drying manure in an electric oven (Memmert ULE-500, Memmert GmbH + Co. KG, Schwabach, Germany) at 105 ± 2 °C for 24 h (Peters et al., 2003). Ash content and volatile solids were calculated after burning total solids in a muffle furnace (L1/12, Nabertherm GmbH, Lilienthal, Germany) at 550 °C for 4 h. Total N was determined with a digester and by distillation (Tecator 2006 digestion unit and Kjeltec 1002 distilling unit, Foss Tecator AB, Höganäs Sweden) according to the Kjeldahl method (Peters et al., 2003); total ammonia N was determined by distillation. All values were calculated on the basis of natural manure.

Statistical analysis

Statistical analysis was performed with the Statistica (Data Analysis Software System, Version 7.0; StatSoft, Tulsa, Oklahoma, USA) software package. Differences were investigated by Student's (t) criterion as well as the ANOVA procedure. Assumption of equal variance of separate groups was verified by Bartlett's test. A significance level of $P \leq 0.05$ was applied to all the statistics.

RESULTS

Manure composition

Water evaporation and adequate loss of initial manure weight occurred during the experimental period (Table 1). Covers reduced manure moisture loss. Water evaporation mostly decreased after manure was covered with plastic film, which was 7.9 to 18.4 times ($P < 0.01$) lower compared with uncovered manure.

At the beginning of the experiment, fresh manure pH was slightly alkaline, but it changed during the storage period. The highest change in pH was detected for manure covered with sawdust at 25 °C; pH was 2.9 times ($P < 0.05$) lower compared with uncovered manure.

For most of the samples, total solids (TS) and volatile solids (VS) content increased at the end of the experiment. The highest change of TS and VS was detected in manure covered with sawdust at 15 °C; TS and VS increased by more than 7.3 and 9.7 times ($P < 0.05$), respectively, compared with uncovered manure. However, VS increase is relative and associated with water evaporation and therefore, with the loss of initial manure weight. During manure storage, biodegradation of volatile solids evolved. The increase in the amount of ash (in most samples) at the end of experiment confirms the above assumption. Physical and chemical characteristics of manure changed satisfactorily.

Table 1. Manure composition and its changes during the experiment.

Manure		Storage temperature	Weight	Analysis					
				pH	TS	VS	Ash	TKN	TAN
		°C	kg		g kg^{-1}				
Fresh			1.00	8.08	109.07	91.83	17.23	6.86	3.82
		Changes in initial weight and manure composition							
						%			
No cover		5	↓31.28	↑ 1.36	↑43.96	↑42.60	↑53.38	↓37.07	↑16.53
Cover	Leca		↓14.20	↑ 5.31	↑11.61	↑12.77	↑ 5.28	↓31.51	↑31.03
	Peat		↓20.17	↓ 0.49	↑37.88	↑38.66	↑34.16	↓42.86	↑22.50
	Sunflower oil		↓ 6.86	↓14.60	↑62.78	↑75.97	↑ 7.19	↓57.33	↓ 5.56
	Sawdust		↓11.74	0.00	↑65.57	↑67.21	↑57.66	↓54.10	↓ 5.00
	Straw		↓ 6.36	↓ 7.84	↑29.05	↑29.74	↑26.40	↓53.85	↑ 8.51
	Plastic film		↓ 1.70	↑ 1.00	0.00	↓ 0.75	↑ 5.60	↓48.94	↑20.00
No cover		15	↓18.87	↓ 6.99	↑11.60	↑ 8.92	↑27.05	↓52.94	↓ 8.15
Cover	Leca		↓ 4.70	↑ 0.93	↑ 2.33	↑ 2.54	↑ 1.22	↓49.32	↑20.69
	Peat		↓ 8.83	↓ 7.61	↑33.23	↑33.61	↑31.19	↓36.36	↑ 2.50
	Sunflower oil		↓ 9.67	↓14.49	↑66.79	↑80.47	↑ 9.80	↓65.33	↑ 1.85
	Sawdust		↓11.19	↓10.94	↑84.67	↑86.53	↑75.68	↓47.54	↓17.50
	Straw		↓ 7.86	↓12.87	↓ 5.56	↓ 7.44	↑ 3.05	↓67.95	↓10.64
	Plastic film		↓ 1.55	↑ 1.58	↓12.11	↓14.39	↑ 3.20	↓57.45	↑30.00
No cover		25	↓12.60	↓ 5.75	↓10.23	↓14.09	↑11.33	↓63.55	↓12.67
Cover	Leca		↓ 9.73	↑ 1.86	↑ 4.04	↑ 2.84	↑10.57	↓45.21	↑ 3.45
	Peat		↓ 8.79	↓12.15	↑22.39	↑18.09	↑45.54	↓41.56	↓57.50
	Sunflower oil		↓12.57	↓11.33	↑62.78	↑74.11	↑15.69	↓70.67	↑16.67
	Sawdust		↓ 6.28	↓16.47	↑62.85	↑61.63	↑73.87	↓49.18	↓40.00
	Straw		↓ 6.94	↓13.22	↓ 8.20	↓10.88	↑ 4.06	↓65.38	↓19.15
	Plastic film		↓ 1.60	↑ 5.87	↓15.89	↓18.15	↓ 0.80	↓61.70	↑55.00

TS: Total solids (dry matter, DM), VS: volatile solids (organic matter), TKN: total Kjeldahl N, TAN: total ammonia N.

Total N content decreased in all the samples at the end of the experiment. The highest change in initial TKN was found at 25 °C for manure covered with sunflower oil; it was 11.2% ($P < 0.01$) lower than uncovered manure. The highest amount of initial TKN remained in the manure covered with leca at 5 °C; it tended to be 15.0% ($P = 0.08$) higher compared with uncovered manure.

Initial TAN content varied inconsistently depending on the type of cover and the temperature. The highest TAN increase was at 25 °C for manure covered with plastic film. In contrast, the highest TAN decrease was found at the same temperature, but for manure with a peat cover. At 15 and 25 °C, TAN decreased when no cover was used, but the opposite occurred at the lowest temperature.

Gas emissions

Leca cover. The ANOVA procedure showed that leca cover had a significant impact on H_2S, CO, and CO_2 emissions; it also tended to affect NH_3 emission. Mean differences between H_2S, CO, and CO_2 emissions from manure covered with leca resulted in a reduction of 74.0% ($P < 0.05$), 57.1% ($P < 0.05$), and 40.4% ($P < 0.01$), respectively, compared with uncovered manure. The NH_3 emission rates from manure with a leca cover tended to be 34.6% ($P = 0.14$) lower than uncovered manure. However, the leca cover was not the factor affecting CH_4 and NO emissions.

Emission rates of all the mentioned gases depended on storage temperature. Generally, a higher emission was detected at a higher storage temperature (Table 2). The impact of covering manure on gas emissions depended on the temperature regime being used (Figure 2). The emissions of H_2S and CO_2 decreased in all the temperature regimes after manure was covered with leca, but the highest reduction was at 5 °C; it was 100.0% ($P < 0.05$) and 48.5% ($P < 0.01$) lower, respectively, than uncovered manure. Carbon monoxide emissions decreased only at 5 and 25 °C. The emission of NH_3 from covered manure tended to reach the highest reduction at 5 °C compared with 5 and 25 °C.

Peat cover. Peat cover had a significant impact on CH_4, NH_3, CO, and CO_2 emissions. The emissions of CH_4, NH_3, and CO_2 from covered manure were 88.5% ($P < 0.01$), 43.8% ($P < 0.01$), and 30.0% ($P < 0.01$) lower, respectively, than uncovered manure. The CO emission was up to 6 times ($P < 0.01$) higher in covered than uncovered manure. However, differences between NO and H_2S emission rates from covered and uncovered manure were not significant.

The emissions of CH_4 and NH_3 decreased in all the temperature regimes used after manure was covered with peat. The highest reduction of CH_4 emission was at 5 °C, which was 100.0% ($P < 0.01$) lower than uncovered manure. The highest reduction of NH_3 emission was at 25 °C, which was 67.3% ($P < 0.01$) lower than uncovered manure. The emission of CO_2 from covered manure decreased only at 5 and 25 °C. The highest increase of CO emissions was at 5 °C, and it was up to 15 times ($P < 0.01$) higher than uncovered manure.

Sunflower oil cover. The sunflower oil cover had a significant impact on NO, H_2S, NH_3, and CO emissions. The emissions of NO, H_2S, and NH_3 from covered manure were 50.3% ($P < 0.05$), 50.2% ($P < 0.05$), and 45.9% ($P < 0.01$) lower, respectively, than uncovered manure. Carbon monoxide emission was 4.8 times ($P < 0.01$) higher in covered manure than uncovered manure. However, the differences between CH_4 and CO_2 emission rates from covered and uncovered manure were not significant.

Table 2. Effect of floating covers and temperature on gas emission rates from liquid pig manure.

Manure		Storage temperature	Emission rates[1]					
			CH_4	NO	H_2S	NH_3	CO	CO_2
		°C	mg m^{-2} h^{-1}					
No cover		5	31.67	0.07	0.03	3.17	0.05	2726.71
Cover	Leca		0.00	0.00	0.00	0.32	0.00	1404.12
	Peat		0.00	0.01	0.00	2.81	0.81	1383.80
	Sunflower oil		0.00	0.33	0.35	2.42	1.57	1474.04
	Sawdust		0.00	0.00	0.00	3.54	0.00	123.16
	Straw		0.00	0.10	0.00	3.97	0.02	821.12
	Plastic film		0.00	0.02	0.05	0.29	0.00	1564.69
No cover		15	138.09	0.67	3.71	9.97	0.11	7230.11
Cover	Leca		66.63	0.34	0.22	1.85	0.21	4977.19
	Peat		6.08	0.32	0.09	6.37	0.35	5527.51
	Sunflower oil		175.15	1.61	9.47	16.24	1.05	3949.03
	Sawdust		0.00	0.06	0.05	6.12	0.00	417.88
	Straw		101.12	0.13	0.49	7.21	0.05	1546.42
	Plastic film		6.15	0.02	0.09	1.39	0.00	3205.40
No cover		25	282.13	5.54	20.62	31.75	0.86	12845.30
Cover	Leca		162.59	1.90	0.75	4.76	0.67	10757.76
	Peat		75.59	12.53	8.59	10.37	4.25	16411.17
	Sunflower oil		404.16	2.68	16.90	25.51	0.55	8849.57
	Sawdust		0.00	10.19	5.11	7.65	2.96	3125.10
	Straw		412.64	2.56	2.25	14.13	1.60	7348.44
	Plastic film		18.30	0.29	0.40	4.78	0.02	4400.48

[1]Mean value for 37-d measurement period.

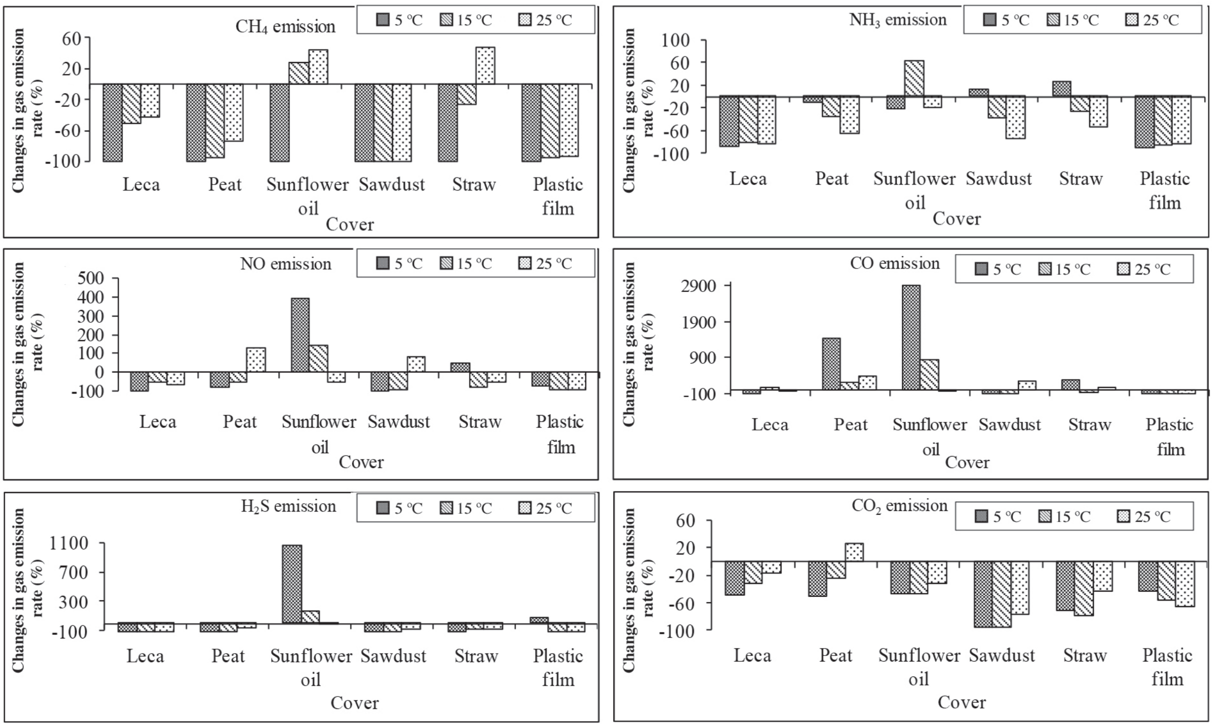


Figure 2. Effect of covers on gas emissions from manure at different storage temperatures.

Raising the temperature was the factor that sustained the reduction of NO and H_2S emission by using sunflower oil cover. In contrast, the highest reduction of NH_3 emission by the cover was at 5 °C, which was 23.8% ($P < 0.01$) lower than uncovered manure stored at 15 and 25 °C. The increase of CO emission from covered manure at 5 °C was 3.4 times ($P < 0.01$) higher than at 15 °C. The highest increase of CO emission after covering the manure was at 5 °C, which was 3.4 times ($P < 0.01$) higher than at 15 °C.

Sawdust cover. The sawdust cover had a significant impact on CH_4, H_2S, NH_3, and CO_2 emissions; it also tended to affect CO emission. These emissions from covered manure were 100.0% ($P < 0.01$), 87.6% ($P < 0.01$), 73.4% ($P < 0.01$), and 71.6% ($P < 0.01$) lower, respectively, than uncovered manure. The CO emission rates from manure with a sawdust cover tended to be 3.1 times ($P = 0.05$) higher compared with uncovered manure. However, the sawdust cover was not the factor affecting NO emission.

The emissions of CH_4, H_2S, and CO_2 decreased in all the temperature regimes after sawdust cover was used. The reduction of CH_4 emission was the same, independently of the temperature regime. The highest reduction of H_2S and CO_2 emissions when manure was covered occurred at 5 °C, which was 100.0% ($P < 0.01$) and 95.5% ($P < 0.01$) lower, respectively, than uncovered manure. The highest reduction of NH_3 emission was at 25 °C; it was 75.9% ($P < 0.01$) lower than uncovered manure. Carbon monoxide emission from covered manure tended to increase only at 25 °C, but the opposite occurred at lower temperatures of 5 and 15 °C.

Straw cover. Straw cover had a significant impact on H_2S, NH_3, CO, and CO_2 emissions, and they also tended to affect NO emission. The emissions of H_2S, NH_3, and CO_2 from covered manure were 92.1% ($P < 0.01$), 64.4% ($P < 0.01$), 39.9% ($P < 0.01$), and 71.6% ($P < 0.01$) lower, respectively, than uncovered manure. The CO emission rates from manure with straw cover was 10.8 times ($P < 0.01$) higher than uncovered manure. The NO emission rates from manure with straw cover tended to be 50.4% ($P = 0.13$) lower than uncovered manure. However, straw cover was not the factor affecting CH_4 emission.

The emissions of H_2S and CO_2 decreased in all the temperature regimes after manure was covered with straw. The reduction of NH_3 emission by covering manure was found only at 15 and 25 °C. A similar trend was observed for NO emission. The highest increase of CO emission after manure was covered occurred at 5 °C, which was 3.2 times ($P < 0.01$) higher than at 25 °C.

Plastic film cover. Plastic film cover had a significant impact on the emission of all measured gases: CH_4, NO, H_2S, NH_3, CO, and CO_2. Their emissions from covered manure were 91.5% ($P < 0.01$), 92.0% ($P < 0.05$), 78.1% ($P < 0.05$), 54.7% ($P < 0.01$), 98.4% ($P < 0.01$), and 67.1% ($P < 0.01$) lower, respectively, than uncovered manure.

The highest reduction of CH_4, NH_3, and CO emissions with covered manure was achieved at 5 °C rather than at15 and 25 °C. In contrast, H_2S emission decreased only at 15 and 25 °C. The highest reduction of NO and CO_2 emissions was at a higher temperature. At 25 °C, the reduction effect of cover on NO and CO_2 emissions was 1.3 ($P < 0.05$) and 1.5 times ($P < 0.01$) higher, respectively, compared with 5 °C.

DISCUSSION

The results of this study showed that the impact of some floating covers on the emission of separate gases can be unequal. Covers can help to decrease the losses of some gases, but increase others. Furthermore, the effect of covers on gas emission varied depending on storage temperature.

In our study, methane emission decreased after covering manure with peat, sawdust, or plastic film compared with uncovered manure. This can be explained by the oxidation of CH_4 inside the cover. Studies by Ambus and Petersen (2005), Petersen and Ambus (2006), Petersen et al. (2009) demonstrated that surface crust, formed on top of animal slurry, provides a habitat for CH_4 oxidation activity, that is, microbial oxidation of CH_4 to CO_2. Therefore, the CH_4 concentration can be reduced in the presence of surface crust. According to Petersen and Ambus (2006), a similar effect can happen in both natural surface crust and artificial floating cover. In our study, an ambiguous effect was found after using plastic film cover. The permeability of this cover was low (there were only small bleeders installed to release produced gases), so the cover mostly suppressed the dissolution of air oxygen into liquid manure, and CH_4 oxidation activity should be poor. However, in our study, the mean – 91.5% reduction of methane emission was achieved after covering manure with plastic film. Analogous results (88% reduction) were detected by Hansen et al. (2006), who covered manure with polyethylene. Hudson et al. (2006) also confirmed that covers do not alter methane emission rates. It is possible that the effect of covering may vary not only depending on the type of cover but on other factors, such as storage time and the presence of inoculum of methanogenic microorganisms, which may also be important; however, it needs to be confirmed by future studies.

In our study, differences between CH_4 emissions from manure with straw cover and uncovered manure were not significant. However, the results of some other studies were also controversial. In the study by VanderZaag et al. (2009), a reduction of CH_4 emission from 24% to 28% was recorded after covering manure with straw. That could be the result of CH_4 oxidation. However, Amon et al. (2006) and Berg et al. (2006) demonstrated that straw can increase CH_4 emission. According to our study, the impact of straw cover on CH_4 emission could depend on storage temperature.

In our study, various covers generally helped to decrease NH_3 emission; this supports the concept that covering manure is beneficial. Portejoie et al. (2003) and Berg et al. (2006) also found that various materials used for covering manure have a reduction effect on NH_3 emission. In our experiment, the best reduction of NH_3 emission was achieved by covering manure with three types of covers: sawdust, straw, and plastic film cover. The highest average reduction of NH_3 emission in our study was 73%. A higher reduction (99%) was detected by Portejoie et al. (2003) during storage of pig slurry covered with plastic film. They also found that NH_3 emission was reduced by 93%, 77% to 100%, and 93% to 98% when using oil, peat, and zeolite, respectively. The results most similar to those of our experiment were found in the study by Miner et al. (2003) where the cover, manufactured from recycled polyethylene chips topped with a geotextile layer containing zeolite particles, was tested and a reduction of 80% of NH_3 emission was detected. Similarly, Bicudo et al. (2004) found a reduction of NH_3 emission from swine manure after covering it with geotextile. A reduction of NH_3 emission was also found by Hansen et al. (2006) after covering separated pig manure with polyethylene, but it was 4.6 times lower than our result after using plastic film cover.

As it was shown in our study, straw cover has a high reduction effect on NH_3 emission (up to 64%). In the study by VanderZaag et al. (2009), a higher reduction was found from 78% (for 15-cm straw layer) to 90% (for 30-cm straw layer). However, in our study, the thickness of straw cover was several times lower than that in the abovementioned study; this might have caused the difference. For the straw, leca, peat, and sawdust cover tests, we used the same thickness to allow a comparison of the effect of different covers on the same gas emission. A thickness of covers similar to those in our study, were used by Portejoie et al. (2003) and a high emission reduction effect was found that supports the validity of our choice of cover thickness.

Our results showed that using covers can generally decrease H_2S emission (with the exception of peat). This agrees with the results by Bicudo et al. (2004), who found a reduction of H_2S flux after covering swine manure storage ponds with a geotextile cover. In our study, the highest reduction of H_2S emission was achieved by using straw, which was the most permeable of all the covers. The reduction of H_2S emission using floating covers can be explained by microbial oxidation. A permeable floating cover is similar to a biofilter. Bacteria and fungi living on biofilters (mainly made of wood chips) can oxidize volatile organic compounds and oxidizable inorganic gases, as well as vapors, including hydrogen sulfide and ammonia emission from swine facilities.

In our experiment, the temperature was the factor that affected gas emission, In general, the results of our study support the concept that gas emission rates increase at higher temperatures (Van der Stelt et al., 2007; Blunden and Aneja, 2008; You et al., 2008; Wang et al., 2010).

CONCLUSIONS

The results of our study showed that both cover and temperature have a noticeable impact on gas emission from liquid pig manure. Different covers had a different effect on separate gas emissions; the impact of using a cover was also associated with storage temperature. In general, the plastic film cover was the most efficient because this type of cover reduced the emissions of all measured gases. In this case, mean emission reductions were: CH_4 91.5% ($P < 0.01$), NO 92.0% ($P < 0.05$), H_2S 78.1% ($P < 0.05$), NH_3 54.7% ($P < 0.01$), CO 98.4% ($P < 0.01$), and CO_2 67.1% ($P < 0.01$). Other covers had an inconsistent impact on separate gas emissions. However, covers generally helped to decrease NH_3, H_2S, and CO_2 emissions.

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