Methane emissions from dairy cow and swine manure slurries stored at 10°C and 15°C

D.I. Massé, F. Croteau, N.K. Patni and L. Masse

Agriculture and Agri-Food Canada, Dairy and Swine Research and Development Centre. P.O. Box 90, 2000 Road 108 East, Lennoxville, Québec, Canada J1M 1Z3. Contribution Number: 759.

Massé, D.I., Croteau, F., Patni, N.K. and Masse, L. 2003. **Methane emissions from dairy cow and swine manure slurries stored at 10°C and 15°C**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **45**: 6.1-6.6. Livestock waste represents a potentially important source of methane (CH_4) emissions, but little experimental data are available on CH_4 production from manure stored on farms. The objective of this study was to determine the effect of slurry characteristics (high and low total solids (TS) contents), temperature (10 and 15°C), and storage duration (180 and 272 days) on methane emissions from dairy cow and swine manure slurries. The manure was stored in closed 232-L plastic barrels simulating the anaerobic conditions of a farm-scale storage tank. Storage conditions and manure characteristics were typical of Canadian commercial livestock farms. Over the 272-day storage period, barrels filled with swine manure produced from 1.32 to 3.81 L CH_4 per L of manure (L/L) at 10°C and from 7.34 to 7.43 L/L at 15°C. When evaluated on a per kg of volatile solids (VS) basis, methane production at 15°C was significantly higher at low (205.1 ± 25.58 L/kg) than at high (89.49 ± 25.62 L/kg) TS contents. Total methane production from dairy cow manure stored at 10°C ranged from 0.26 to 0.28 L/L. At 15°C, average methane emissions from dairy cow manure significantly increased from 0.33 L/L at high TS to 3.77 L/L at low TS content. Methane emissions from low TS dairy cow manure stored at 15°C were mostly recorded between days 180 and 272, due to an increase in both biogas production and methane content of the biogas. Under similar storage conditions, swine manure produced more methane than dairy cow manure. Results suggested that CH_4 emissions depend on the interaction between a number of variables, including physico-chemical characteristics and type of manure, temperature, and storage duration. Results also indicated that on typical Canadian farms, CH_4 emissions from manure storage tanks over the late fall, winter, and early spring period should be very small, because manure temperature remains substantially below 10°C. However, manure slurry should be removed daily or weekly from swine buildings, where manure temperature is maintained above 10°C. During the late spring, summer, and early fall period, CH_4 emissions from manure tanks could be substantially reduced by recommending storage periods shorter than 150 days and frequent land applications. The use of below ground storage tanks would also contribute to maintain lower manure temperatures during the summer and thus minimise CH_4 emissions. **Keywords**: methane emission, manure storage, swine manure, dairy cow manure, anaerobic conditions.

Les déchets animaux représentent une source potentiellement importante d'émissions de méthane. Cependant, peu de données existent sur les quantités de méthane émanant des fosses à fumier. La présente étude vise à déterminer l'incidence des caractéristiques du lisier (haute et basse teneurs en solides), de la température (10 et 15°C) et de la durée d'entreposage (180 et 272 jours) sur les émissions de méthane à partir de lisier de vache laitière et de porc. Les lisiers étaient entreposés dans des barils de 232 litres simulant les conditions anaérobies des structures d'entreposage. Les caractéristiques du lisier et les conditions d'entreposage étaient représentatives de ce que l'on retrouve sur les fermes d'élevage canadiennes. Après 272 jours d'entreposage, la production totale de méthane à partir de lisier de porc a varié de 1,32 à 3,81 L par litre de fumier (L/L) à 10°C et de 7,34 à 7,43 L/L à 15°C. La production de méthane en L par kg de VS était plus élevée, de façon significative, dans le lisier porcin à haute teneur qu'à basse teneur en solides. À 10°C, la production totale de méthane à partir du lisier de vache laitière a varié de 0,26 à 0,28 L/L. À 15°C, les émissions de méthane ont augmenté de 0,33 L/L pour le lisier de vache à haute teneur en solides à 3,77 L/L pour celui à basse teneur en solides. Les émissions de méthane à partir de lisier de vache laitière à basse teneur en solides et entreposé à 15°C ont été principalement enregistrées entre les jours 180 et 272, en raison de l'augmentation de la production de biogaz et de la teneur en méthane du biogaz. Dans des conditions similaires d'entreposage, le lisier de porc a produit plus de méthane que le lisier de vache laitière. Les résultats montrent que les émissions de méthane à partir de structures d'entreposage de fumier dépendent de l'interaction entre plusieurs variables, telles les caractéristiques physico-chimiques et le type de fumier, la température et la durée d'entreposage. Les résultats de l'étude montrent que sur la plupart des fermes canadiennes, les émissions de méthane à partir des structures d'entreposage pendant la période couvrant la fin de l'automne, l'hiver et le début du printemps sont négligeables parce que la température du fumier reste nettement inférieure à 10°C. Par ailleurs, le fumier devrait être évacué des bâtiments d'élevage sur une base quotidienne ou hebdomadaire, car les températures du lisier dans les caniveaux sont généralement au-dessus de 10°C. Pendant la période couvrant la fin du printemps, l'été et le début de l'automne, on peut réduire considérablement les émissions de méthane en entreposant le fumier pendant moins de 150 jours et en l'appliquant plus fréquemment au champ. L'utilisation de fosses partiellement enfouies permettrait également de diminuer la température du fumier. **Mots clés**: émissions de méthane, entreposage du fumier, fumier de porc, fumier de vache laitière, conditions anaérobies.

INTRODUCTION

Methane is one of the well-recognised greenhouse gases (GHG) that accumulates in the atmosphere due to human activity. Rodhe (1990) estimated that on a mass basis, the contribution of methane to the GHG effect is 30 times that of CO_2. Atmospheric concentrations of methane have increased by 90% since 1600, with a rapid rise starting in the early 20th century (Pearman et al. 1986). In past decades, the annual increase in atmospheric methane concentrations ranged from 0.8 to 1.0% (Blake and Rowland 1988; Khalil et al. 1993; Lelieveld and Crutzen 1992). It was estimated that a 10% reduction in CH_4 emissions would reduce the warming potential of the planet by 1°C, which is equivalent to 25% of the expected warming during the next century (Hogan et al. 1991; Thompson et al. 1992). However,

Table 1. Manure types and storage conditions used in the experiment.

Manure type	Total solids (%)	Temperature (°C)	Number of barrels per treatment
Dairy cow	9.2	10	2
		15	4
	4.2	10	2
		15	2
Swine	11.3	10	3
		15	3
	4.9	10	2
		15	2

continued increases in CH_4 emissions are expected in the absence of mitigation strategies (Johnson et al. 1996).

Livestock waste is a potentially important source of CH_4 emissions, particularly in developed countries where a large number of animals are intensively housed (Moss 1993). Husted (1993) estimated that animal manure accounts for 6 to 10% of total planetary CH_4 emissions due to human activity. Methane production from stored manure will depend on animal species, ration, age of animal, collection method, storage period, temperature, and amount of foreign material (i.e. bedding) incorporated into the waste (Chen et al. 1988). Methane emissions from livestock manure are expected to increase in the coming decade, mainly due to an intensification of animal production and the increasing use of liquid-based manure management systems (Gibbs and Woodbury 1993).

Little experimental data are available on CH_4 emissions from manure stored on farms, and recent reported values reflect wide variations (Husted 1994). The main objective of this paper was to quantify CH_4 emissions from swine and dairy cow manure slurries at two total solids (TS) contents and stored at low temperatures typical of farm storage in cool climatic regions. The study was conducted in laboratory-scale closed systems, from which biogas produced over the entire surface of the slurry was collected. Jackson et al. (1994) showed that biogas production from laboratory-scale closed systems is representative of farm-scale manure storage facilities. Small-scale closed systems prevent possible bias caused by the sampling of 'hot spots' (microsites where increased methanogenesis occurs due to the presence of easily decomposable organic matter, Husted 1993) in large manure storage structures.

MATERIALS and METHODS

Experimental set-up

Manure types and storage conditions used in the experiment are presented in Table 1. The dairy cow and growing-finishing pig manure was collected from a tank directly underneath the animals. In the laboratory, the manure was mixed and immediately stored in 232-L closed plastic barrels (880 mm high by 580 mm diameter) simulating the anaerobic zone of a farm-scale storage tank. Some barrels were completely filled with freshly collected manure (high TS manure), while other barrels were half-filled with manure and half-filled with tap water (low TS manure). The barrels were placed in two controlled environment chambers maintained at 10 and 15°C, respectively. Each treatment combination was originally tested in four replicate barrels. However, certain barrels developed leaks and their biogas production had to be removed from final analysis. The actual number of barrels that were included in result analysis is indicated in Table 1. The gas collection period extended for 272 days.

Biogas measurement apparatus

A tube was attached to the barrel covers and equipped with a gas sampling port fitted with a septum and connected to a wet-cup gas meter. All fittings and connections were sealed with silicone to prevent gas leaks. The wet-cup gas flow meters were calibrated prior to the experiment and the calibration was verified at the end of the storage period. The cups were calibrated at about 15°C with air bubbles slowly blown into the cups. The air bubbles displaced a column of water graduated to the nearest milliliter. As soon as the cup tipped (after approximately 100 mL), the air entry was stopped and total volume of displaced water was measured. The calibration was accurate within approximately 1%.

Sample and data analyses

Samples were analysed for soluble and total chemical oxygen demand (SCOD and TCOD) by the closed reflux colorimetric method (APHA 1992). Total solids concentration was determined by drying a 10-mL sample for 24 h at 105°C. Volatile solids (VS) concentration was measured by incinerating the dry sample at 550°C for 2 h. Ammonia nitrogen (NH_4-N) and total Kjeldahl nitrogen (TKN) were analysed according to the macro-Kjeldahl method (APHA 1992) with a Tecator 1030 Kjeltec auto-analyser (Tecator AB, Höganäs, Sweden). Alkalinity was determined by titration to a pH of 4.38, and pH was measured with a pH meter (PHM92 Lab, Radiometer Analytical, Bagsvaerd, Denmark). Volatile fatty acids (VFAs) were analysed using a Perkin Elmer Autosystem gas chromatograph (Perkin-Elmer Corporation; Norwalk, CT) equipped with a high-resolution megabore column (J&W Scientific; Folsom, CA) connected to a flame ionisation detector.

Gas samples were collected periodically with a 10-mL syringe and immediately analysed for CH_4, CO_2, N_2, and H_2S content using a HachCarle 400 AGC gas chromatograph. The CH_4 emission rates were calculated as:

$$F_{CH_4} = \frac{[CH_4]Q_g}{V} \quad (1)$$

where:

F_{CH4} = CH_4 emission rate (L CH_4 m^{-3} of manure d^{-1}),
$[CH_4]$ = mean CH_4 content of biogas (L CH_4/L of biogas),
Q_g = measured biogas flux rate (L biogas/d) at a constant pressure of 100 mm of water, and
V = volume of manure in the barrel (m^3).

The volume of methane was adjusted to a standard temperature and pressure of 0°C and 1 atm, respectively.

Significant differences in results were estimated using the Duncan's multiple range test in SPSS 9.0 for Windows. Significant differences were set at $P < 0.05$.

Table 2. Average characteristics of the diary cow and swine manure slurries.

Parameter	Pig manure				Dairy cow manure			
	High TS		Low TS		High TS		Low TS	
	Average	S.D.	Average	S.D.	Average	S.D.	Average	S.D.
TCOD (g/L)	162.93	11.81	70.17	23.33	91.05	4.95	54.10	1.71
SCOD (g/L)	34.19	7.25	15.44	8.02	29.92	1.76	14.97	1.49
TS (g/L)	112.94†	NA‡	48.64	13.76	92.23	1.68	41.96	2.50
VS (g/L)	83.07†	NA‡	35.78	11.10	77.48	1.72	33.44	1.41
pH	7.18	0.09	7.06	0.03	6.78	0.06	6.78	0.01
TKN (g/L)	8.84	0.60	3.50	0.63	3.90	0.03	2.06	0.06
NH_4-N (g/L)	5.74	0.35	2.48	0.44	2.12	0.01	1.12	0.04
Acetic (g/L)	5.81	0.21	2.91	0.60	5.45	0.24	3.38	0.14
Propionic (g/L)	2.73	0.23	1.25	0.21	1.71	0.03	1.04	0.06
Butyric (g/L)	1.22	0.54	0.56	0.14	1.22	0.04	0.66	0.02

† Determined using average TCOD:TS and TCOD:VS ratios measured in the barrels containing low TS swine manure
‡ Not applicable (see note above)

RESULTS and DISCUSSION

Physico-chemical characteristics of the manure

Manure characteristics are given in Table 2. The TCOD, TKN, and ammonia-N concentrations were approximately twice as high in swine than dairy cow manure. On the other hand, the SCOD and VFA concentrations, representing the readily available organic fraction for biological degradation, were in the same range for both manure types.

Manure at low TS content had lower concentrations of compounds, such as VFAs and ammonia, that could affect methane production. Acetic acid is the direct precursor of methane. In high concentrations, however, both VFAs and ammonia can inhibit methanogenesis and curtail CH_4 production. Most parameters presented in Table 2 were 40 to 60% lower in low than high TS manure. Variations in the dilution ratio for the different parameters were probably caused by the difficulty of accurately sampling the solids compared to the liquid fraction. Variations in slurry characteristics fall within the expected range for liquid manure stored on Canadian commercial farms.

Methane production from dairy cow manure

Table 3 gives total and daily CH_4 production over two storage periods (180 and 272 days) that are representative of manure management practices on Canadian livestock farms.

Methane production from dairy cow manure was consistently higher at 15°C than 10°C, but the difference was significant at low TS after 272 days of storage only. At the end of the experimental period, total CH_4 production from dairy cow manure ranged from 0.26 to 0.28 L per L manure (L/L) at 10°C and from 0.33 to 3.77 L/L at 15°C. The significantly higher methane production from low TS dairy cow manure stored at 15°C was due to an increase in both biogas production and methane content of the biogas between days 180 and 272 of storage (Figs. 1 and 2). During the initial 180 days at 15°C, low TS dairy cow manure produced an average of 5.59 L of biogas (mixture of methane and carbon dioxide) per cubic meter of manure per day (L m^{-3} d^{-1}). Between days 180 and 223, biogas production rate steadily increased to a maximum of 95.2 L m^{-3} d^{-1}, while methane content of the biogas increased from 55.9 to 74.0%. After 180 days of storage, total methane production from low TS dairy cow manure stored at 15°C averaged 0.39 L/L and was not significantly ($P < 0.05$) higher than at 10°C (Table 3). Total CH_4 production increased almost ten fold in the following 92 days. After 272 days of storage, a total methane production of 112.8 ± 20.8 L per kg of VS was recorded for the low TS dairy cow manure stored at 15°C (Table 3). This represented about half the methane potential of 200 L per kg of VS estimated for cattle slurry (Hashimoto et al. 1980; Hashimoto 1984). Total CH_4 emissions from manure storage tanks may thus be highly dependent on storage time.

The concentration of ammonia and VFAs, which could be inhibitory to the methanogens, was reduced in low TS compared to high TS dairy cow manure. Dilution may thus have contributed to the higher methane content in the biogas from the low than the high TS dairy cow manure at both temperatures (Fig. 2). The combined effect of dilution and higher storage temperature probably allowed the growth of a more active methanogen population. However, the development of a significant methanogenic activity required over 5 months of storage at 15°C.

Over 272 days, daily CH_4 production rate from low TS dairy cow manure stored at 15°C averaged 14.83 L m^{-3} d^{-1} (Table 3). This average rate is similar to the value of 12 L m^{-3} d^{-1} reported by Husted (1994) for a one-year farm storage of dairy cow manure with a TS content of 6.5% at a mean annual temperature of 11.2°C. For all other treatments with dairy cow manure, average daily rates ranged from 1.06 to 1.34 L m^{-3} d^{-1}. These rates are consistent with those reported by Patni et al. (1995) and Jackson et al. (1993) for dairy cow manure stored in a slurry tank at temperatures varying between 14 and 23°C. However, annual average rates are misleading given the large temporal variation observed in this study. Coefficients of variation (standard deviation over average) for average daily CH_4 production were well above 100% in most treatments.

Table 3. Methane production (adjusted to 0°C and 1 atmosphere) from dairy cow and swine manure slurries for storage periods of 180 and 272 days.

Manure type	Solids content (%)	Storage time			
		180 days		272 days	
		10°C	15°C	10°C	15°C
		Total methane production (L CH_4 per L manure)			
Dairy cow	9.2	0.24[†] ± 0.03 [a‡]	0.28 ± 0.03 [a]	0.26 ± 0.03 [a]	0.33 ± 0.02 [a]
	4.2	0.27 ± 0.02 [a]	0.39 ± 0.23 [a]	0.28 ± 0.02 [a]	3.77 ± 0.70 [cd]
Swine	11.3	2.84 ± 0.57 [bc]	5.20 ± 1.32 [d]	3.81 ± 0.71 [cd]	7.43 ± 2.13 [e]
	4.9	0.94 ± 0.03 [a]	4.57 ± 0.91 [d]	1.32 ± 0.08 [ab]	7.34 ± 0.92 [e]
		Total methane production (L CH_4 per kg VS)			
Dairy cow	9.2	3.09 ± 0.34 [a]	3.64 ± 0.34 [a]	3.42 ± 0.37 [a]	4.32 ± 0.23 [a]
	4.2	7.95 ± 0.70 [ab]	11.53 ± 6.83 [abc]	8.36 ± 0.75 [ab]	112.8 ± 20.80 [gh]
Swine	11.3	34.13 ± 6.86 [bcd]	62.62 ± 15.86 [e]	45.82 ± 8.60 [de]	89.49 ± 25.62 [f]
	4.9	26.19 ± 0.93 [abc]	127.8 ± 25.57 [i]	36.99 ± 2.22 [cd]	205.1 ± 25.58 [j]
		Daily methane production rate (L CH_4 per m^3 per day)			
Dairy cow	9.2	1.46 ± 1.31	1.64 ± 1.65	1.06 ± 1.20	1.25 ± 1.43
	4.2	1.68 ± 2.96	2.17 ± 2.61	1.15 ± 2.50	14.83 ± 19.26
Swine	11.3	16.25 ± 6.87	30.00 ± 16.55	14.40 ± 6.46	28.08 ± 13.95
	4.9	5.36 ± 2.75	26.69 ± 5.07	4.97 ± 2.41	27.31 ± 5.05

† Average values are given with their standard deviations (S.D.). For total methane production (L/L and L/kg), the S.D. reflects difference between replicate barrels. For daily methane production rate (L m^{-3} d^{-1}), the S.D. represents the difference between sampling days.
‡ Within each section of the table, values with the same letter are not different at $P<0.05$.

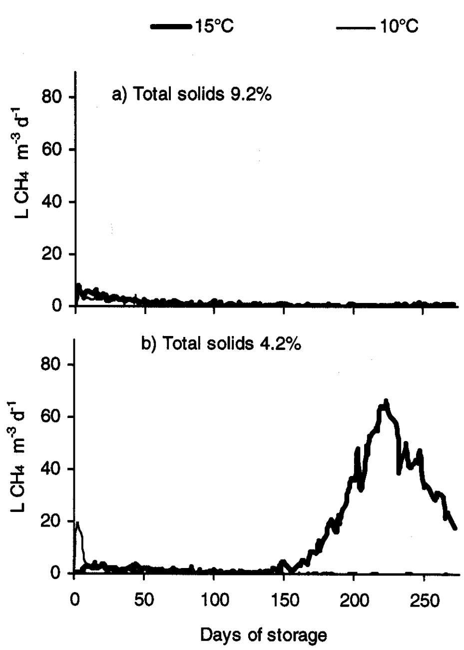

Fig. 1. Methane production (litres of CH_4 at 0°C and 1 atm per m^3 per day) from dairy cow manure stored at 10 and 15°C.

Methane production from swine manure

Under all storage conditions and duration, biogas production and methane content of the biogas was higher in swine than dairy cow manure (Figs. 1 to 4). The difference in total methane production between dairy cow and swine manure was significant for all treatments but for low TS manure stored at 10°C (Table 3). Previous studies also showed that pig slurry VS are a better substrate for methanogens than cattle slurry VS (Husted 1994; Hashimoto et al. 1980; Hashimoto 1984). Methane potential for swine and cattle slurries was estimated at 480 and 200 L per kg of VS, respectively (Hashimoto et al. 1980; Hashimoto 1984). The intense fermentation of the cellulosic material in the rumen of dairy cows leaves less dietary soluble carbohydrates in the fecal material for methanogenesis. Additionally, manure from different animals probably contains different species of anaerobic bacteria, which may be better adapted or acclimatized to inhibitive components such as ammonia.

The effect of temperature on CH_4 production was more important with swine than dairy cow manure. At both TS contents, methane production from swine manure significantly increased with storage temperature (Table 3). At 10°C, methane production also significantly increased, from 1.32 to 3.81 L/L, as TS content was increased from 4.9 to 11.3%. The increase was due to higher biogas production and methane content of the biogas at high TS content (Fig. 4). At 15°C, similar methane

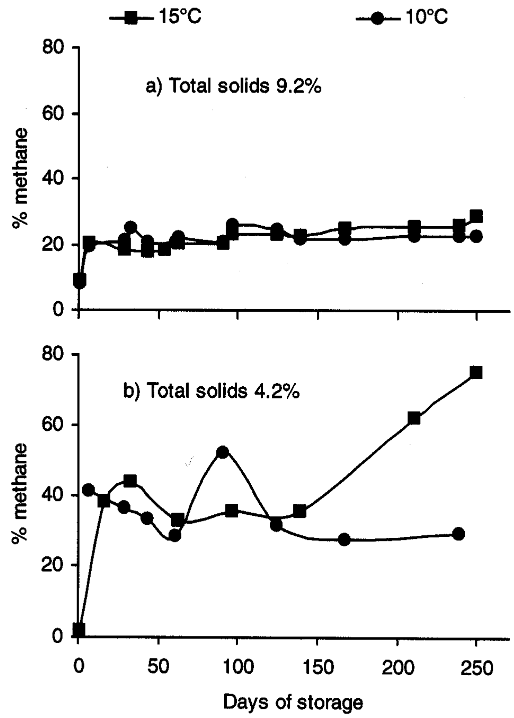

Fig. 2. Methane content in biogas from dairy cow manure stored at 10 and 15°C.

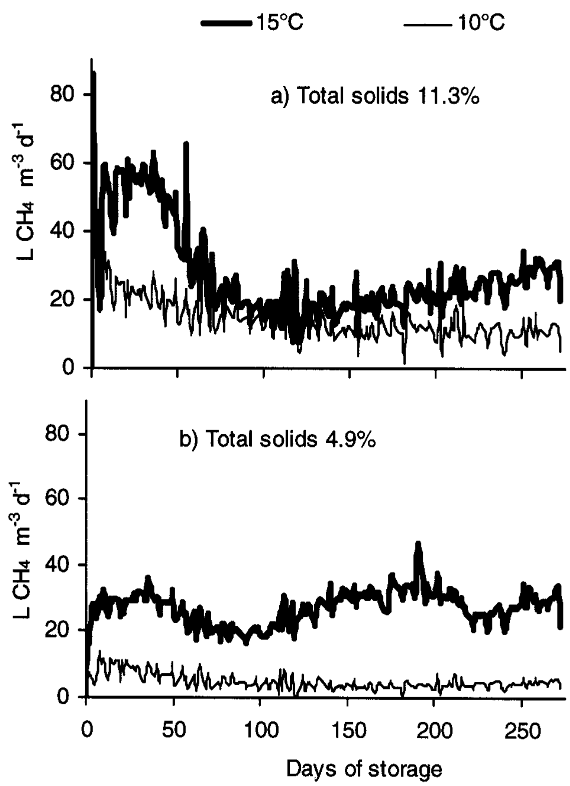

Fig. 3. Methane production (litres of CH_4 at 0°C and 1 atm per m^3 per day) from swine manure stored at 10 and 15°C.

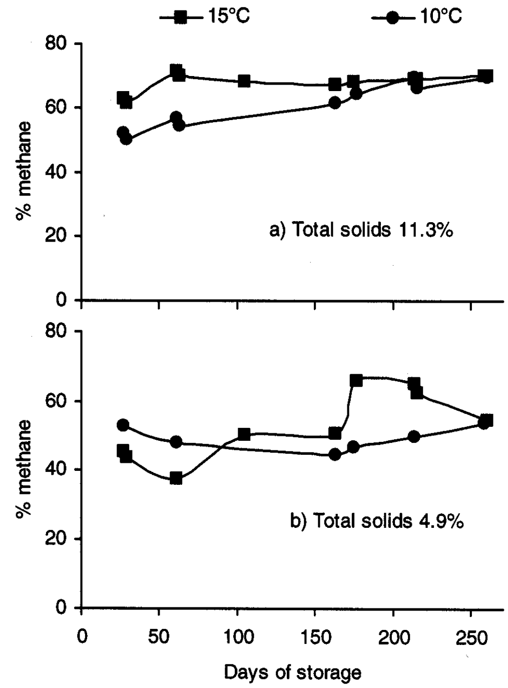

Fig. 4. Methane content in biogas from swine manure stored at 10 and 15°C.

production per volume of manure was recorded at both TS contents, with averages of 7.34 and 7.43 L/L at low and high TS contents, respectively (Table 3). Slightly lower methane content in the biogas was compensated for by overall higher biogas production in the low TS swine manure. However, methane production in liters per kilogram VS increased significantly as TS was reduced at 15°C, with averages of 89.5 and 205.1 L/kg VS in high and low TS swine manure, respectively (Table 3). Swine production units handling manure in a more dilute state may thus produce significantly more methane than those keeping manure in a more concentrated state. However, the effect of dilution may depend on temperature, since volumes of methane per kg of VS were not significantly different at low and high TS content at 10°C (Table 3).

Daily CH_4 production rate ranged from 4.97 to 28.08 L $m^{-3} d^{-1}$. Coefficients of variation were all below 50%. Average daily emissions were consistent with the value of 17 L $m^{-3} d^{-1}$ reported by Husted (1994) for mean annual CH_4 emission rate from pig slurry at a 2.0% TS content and a mean storage temperature of 11.2°C.

CONCLUSION

Temperature, TS content, and storage duration had an impact on CH_4 emissions from dairy cow and swine manure. As storage temperature was increased from 10 to 15°C, total CH_4 emissions increased for all types of manure slurries. Under similar storage conditions, swine manure produced significantly more methane than dairy cow manure. Over the 272-day storage period, barrels filled with swine manure produced from 1.32 to 3.81 L/L at 10°C and from 7.34 to 7.43 L/L at 15°C. When evaluated on a per kg of VS basis, methane production at 15°C was significantly higher at low (205.1 ± 25.58 L/kg) than high

(89.49 ± 25.62 L/kg) TS contents. For dairy cow manure, total methane production ranged from 0.26 to 0.28 L/L at 10°C and from 0.33 to 3.77 L/L at 15°C. Most CH_4 production from low TS dairy cow manure stored at 15°C was recorded between days 180 and 272 of the experiment, due to an increase in both biogas production and methane content of the biogas. These results indicated the importance of storage duration on CH_4 production and the unreliability of data, such as daily methane production rate, averaged over long time periods.

The results also show the complexity of modelling CH_4 emissions from manure storage tanks. Methane emissions depend on a number of variables, including physico-chemical characteristic and type of manure, temperature, indigenous flora, and storage period, which interact differently as the environment changes. For example, more methane was produced from the low than the high TS cow manure at 15°C. However, no difference due to TS content was observed in methane production from cow manure at 10°C. With swine manure, on the other hand, TS content did not influence the CH_4 production per liter of manure at 15°C but had a marked effect at 10°C. The relationships between all variables will have to be better understood before successfully modelling CH_4 emissions from stored manure or accurately estimating CH_4 emissions from stored manure in Canada.

The data presented here should be representative of CH_4 emissions from manure storage tanks in Canada, since the experimental set-up simulated Canadian storage conditions. The study showed that on typical Canadian farms, CH_4 emissions from manure storage tanks over the late fall, winter, and early spring period can be expected to be negligible, because manure temperature remains substantially below 10°C. However, manure slurry should be removed daily or weekly from livestock buildings, where manure temperature is kept above 10°C. During the late spring, summer, and early fall period, methane emissions from manure tanks could be substantially reduced by recommending storage periods shorter than 150 days and frequent land applications of the manure. The use of below ground storage tanks would also contribute to maintain lower manure temperatures and thus minimise CH_4 emissions over the summer. Finally, handling swine manure in a more concentrated form may reduce CH_4 emissions in barns and in storage tanks during the summer, when temperatures are higher.

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