CH_4 EMISSIONS FROM ANIMAL MANURE

ACKNOWLEDGEMENTS

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ABSTRACT

The paper identifies uncertainties in the default emission factors, B_o (biodegradability of manure) and MCF (methane conversion factor), and gives suggestions for improvement of these values. The maximum biodegradability, B_o, is expressed in m^3 CH_4 produced per kg VS (volatile solids). The determination of VS directly includes possible errors, when volatile components are present. Manure will always contain a fraction of volatile fatty acids (VFA). The latter will result in an over estimation of the B_o value. B_o determination should not only include VS analysis but also total chemical oxygen demand (COD) and VFA. Standardisation of the B_o determination, including sampling methods is recommended. The MCF does not only depend on the manure management system used, but also on the temperature of the stored manure, and the handling of the system for example the mean percentage of manure left over (=inoculation) after 'emptying' (use). It is therefore recommended to collect more data on this item, and re-estimate default MCF values with the aid of model calculations. Specifying the MCF values for digesters is recommended because, with the now recommended MCF defaults values (10 percent), controlled anaerobic digestion is expected to always include a relatively high methane emission, which could prevent the implementation of the method. Anaerobic digesters can be constructed in such a way that no or hardly any methane emission occurs.

KEYWORDS

CH_4, emission, animal manure, biodegradability, Volatile Fatty Acids, Volatile Solids, Methane Conversion Factor

1 INTRODUCTION

1.1 Aim of the workshop

The aim of the sectoral meetings is to define guidelines on *good practice*. Issues to be covered will include a process to identify preferred methods, *good practice* in data collection and emission factor development/selection/verification, *good practice* in inventory calculations, and preferred approaches to estimating uncertainties as well as providing transparent documentation, including type and level of presentation.

1.2 Background papers

Two background papers have been produced for the sector workshop methane emission from animal manure. The first paper was prepared by Gibbs et al (1999) and gives an overview of all factors and uncertainties involved in the determination of methane emissions from animal manure.

The present paper tries to identify uncertainties in the default emission factors, B_o and MCF, and gives suggestions for improvement of these values. Furthermore, standardisation of certain determinations as included in the IPCC Tier 2 method is recommended.

2 METHODOLOGICAL ISSUES

2.1 Framework for the best practice method

According to the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines)* the total annual methane emissions for animal type i in a particular climate region is the sum of annual emissions over all applicable manure systems j:

$$CH_4^{\,i} = \Sigma_j B_o^{\,i} \bullet VS_i \bullet MS\%_{ij} \bullet MCF_j$$
$$VS_i = N_i \bullet \overline{vs}_i$$

Where:

CH_4:	Methane emissions (m^3/yr)
B_o:	Biodegradability of manure (m3 CH4/kg VS)
MCF:	Methane conversion factor (%)
MS%:	Manure management system usage (%)
VS:	Total volatile solids produced annually (kg/yr)
N:	Animal number (heads)
$\overline{vs}$:	Average annual volatile solids production per head (kg/head/yr)

It is clear from the IPCC formula above that five important parameters should be known in order to determine the occurring methane emissions. These parameters are evaluated below.

Methane emissions from animal waste

- depends very strongly on the specific manure management system applied as well as the conditions and the manner of how the system operates

Animal number (heads) per type and class of animals (N)

- which disaggregation circumstances should be applied under what circumstances, and
- if data are not available what methods should be considered.

Manure production (VS/head/year) (VS)

The manure production per animal kept under certain conditions will based on feed intake and digestibility of the feed, which in turn depends on:

- region where the animal is kept, and
- type and class of animal.

Methane production Potential (B_o = m^3CH_4/kgVS)

This depends on feed intake and digestibility of the feed, which in turn depends on:

- region where the animal is kept, and
- type and class of animal.

Methane conversion factor (MCF)

The first three parameters are discussed by Gibbs et al. (1999). The last two parameters- B_o -value and MCF-value will be discussed in more detail in this paper.

2.1.1 Methane Production Potential (B_o = m^3CH_4/kgVS)

Within the *IPCC Guidelines* two tiers are distinguished. The first tier is to be used when no or hardly any country- specific data are available. Otherwise the second tier is to be used.

(a) IPCC Tier 1(Default B_o values)

IPCC default values are based on the values as reported by Safley et al (1992). The values are illustrated Table 1.

TABLE 1

PRODUCTION OF VS AND MAXIMUM ANAEROBIC BIODEGRADABILITY OF THE VS

Region	Dairy		Non-dairy		Buffalo		Swine	
	B_o [a]	VS[b]	B_o [a]	VS[b]	B_o [a]	VS[b]	B_o [a]	VS[b]
North America	0.24	5.2	0.17	2.4	0	0	0.45	0.5
Western Europe	0.24	5.1	0.17	2.7	0.1	3.9	0.45	0.5
Eastern Europe	0.24	4.1	0.17	2.7	0.1	3.9	0.45	0.5
Oceania	0.24	3.5	0.17	3	0.1	3.9	0.45	0.5
Latin America	0.13	2.9	0.1	2.5	0.1	3.9	0.29	0.3
Africa	0.13	1.9	0.1	1.5	0.1	3.9	0.29	0.3
Middle East	0.13	1.9	0.1	1.5	0.1	3.9	0.29	0.3
Asia	0.13	2.8	0.1	2.3	0.1	3.9	0.29	0.3
Indian Subcontinent	0.13	2.6	0.1	1.4	0.1	3.1	0.29	0.3

[a] in m^3 CH_4/kg VS

[b] Average VS production for per head per day for the average animal (kg VS/(head.day))

Source: IPCC 1997

The determination of the B_o value is an important aspect with respect to the reliability of the method. In literature, large variations can be found for B_o values for both cattle and pig manure. The B_o values as adapted for the US are also used in the *IPCC Guidelines* for developed countries as it is assumed that typical diets are similar. The values for developing countries are modified, considering that there is less energy in the feed used.

Possible errors during B_o determination

The maximum biodegradability, B_o, is given as m^3 CH_4 produced per kg VS. The determination of VS directly includes possible errors. The VS measurement includes drying and incineration steps. The first gives rise to possible errors when volatile components are present. Manure will always contain a fraction of volatile organic components, viz. volatile fatty acids (VFA). The quantity of VFA will depend on the storage conditions of the used manure. According to Derikx et al. (1994) large losses of VFA can be expected during dry matter determination. Figure 1 presents the percentage recovery of VFA after dry matter determination as a function of the pH for pig, cattle and poultry manure. The results show that at pH values of 7.5, a normal pH for influent animal manure, ca 75% of the VFA is lost.

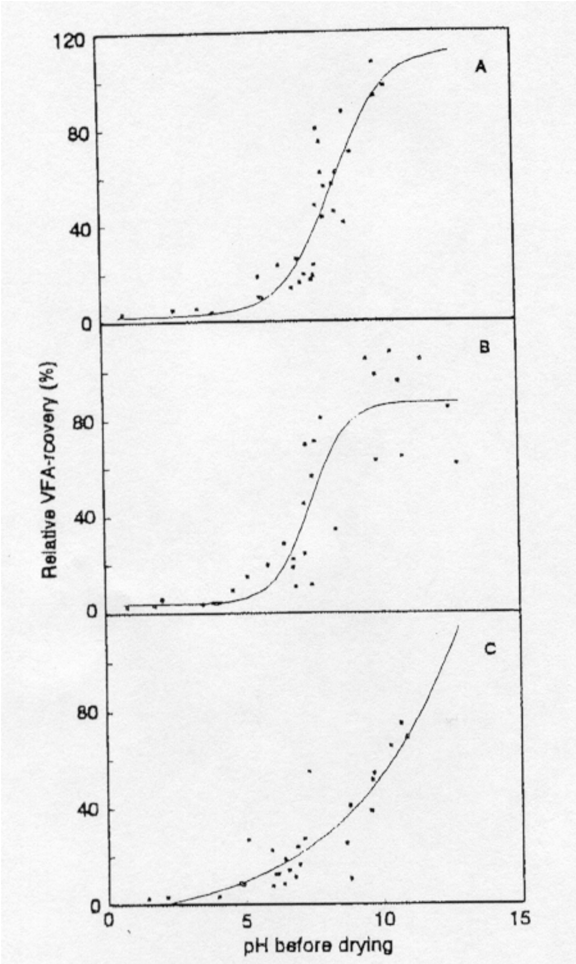

Figure 1 Percentage recovery of VFA after dry matter determination of pig manure (A), cattle manure (B) and poultry manure (C)

Source: Derikx et al., 1994.

As an important part of the VFA will be lost during the determination of the VS, while it will be completely converted to CH_4 gas during the biodegradability test, an over estimation of the B_o value will occur. The magnitude of the error will depend on the fraction of VFA present in the influent manure, which in turn will depend on the conditions during the storage of the manure. Zeeman (1991) presents VFA concentrations for cow manure between 9 and 16 g COD/l, at VS concentrations between 56 and 81 g/l and VFA concentrations for pig manure of 30 g COD/l, at a VS of 78 g/l. V. Velsen (1981) shows VFA concentrations for pig manure lying between 8.7 and 15.9 g COD/l at VS concentrations between 38 and 65 g/l. This means that an error between 10 and 30% in the VS measurement can be made.

Evaluation of the default values based on theoretical considerations.

The suspended solids in animal manure mainly consist of carbohydrates ((hemi) cellulose), some proteins and even less lipids. Table 2 presents some literature values on the composition of cow and pig manure

TABLE 2

COMPOSITION (IN PERCENTAGE OF THE TOTAL SOLIDS) OF ANIMAL MANURE, AS USED BY SEVERAL RESEARCHERS

	Lipids	Proteins	Carbohydrates	Cellulose	Hemi-cellulose	Lignin	Anorg residue	References
Cow	6.1	13.7	59.9				20.3	1
Cow	6.1	15.0	62.1				16.9	1
Cow	7.5	15.6		14.5	19.3	8.2	29.0	2
Cow	3.5	15		17.o	19.0	6.8	28.0	3
Cow	4.0	15+		25.0	2.0	9.0	16.0	6
Pig	12.3	16.0		10.3	17.1	3.7	17.3	2
Pig	7.7	20.9	53.8*	22.9	20.8	10.1	17.6	4
Pig	7.0	28.9					27.0	5

* cellulose, hemi-cellulose, lignin; + (total-N)-(NH4+-N)*6.25

1. Steiner (1983); 2. Wellinger, (1984); 3.Varel, Isaacson and Bryant, 1977), 4. Hobson, Bousfield and Summers (1974); 5. Temper (1983); 6. Robbins, Gerhardt and Kappel (1989).

One gram of VS for 'biological' sludge's is normally considered to be equal to 1.4 g COD. Considering the conversion factors for the different polymers shown below and the composition as shown in Table 3, this overall conversion factor is a reasonable estimate for animal manure, provided that fresh manure is involved with no or hardly any VFA present.

TABLE 3

CONVERSION FACTORS FOR DIFFERENT POLYMERS TO COD

Polymer	Structure formula	Equivalent to
1 g carbohydrates	$C_6 H_{12} O_6$	1.07 g COD
1 g lipid		2.91 g COD (Sayed, 1987);
1 g protein	$(C_4 H_{1.6} O_{1.2} N)x)$	1.5 g COD (Sanders et al. 1996)

Hashimoto (1984) uses pig manure with concentrations of 33.5-77.1 g VS/l and 38.5 - 96.3 g COD/l. Based on the results of continuous experiments, a B_o value of 0.48 m³ CH_4/kgVS is determined. Based on the reported COD and VS concentrations, a COD/VS ratio between 1.15 and 1.25 can be calculated. This means that the B_o should be equal to 0.44 - 0.4 m³ CH_4/kg COD. The latter is impossible as the theoretical maximum methane production is 0.35 m³ CH_4/kg COD. Also the results of the effluent COD measurements as reported by Hashimoto (1984) show that the reported gas production (m³ CH_4/kgVS) is a factor of 2 higher than can be re-calculated based on the removed COD. Hashimoto (1983) also determines a B_o value of 0.49 m³ CH_4/kgVS based on batch experiments at 35 and 55°C, using a similar pig manure with a COD/VS ratio of 1.01-1.2 .

Chen (1983) makes use of the above-mentioned B_o values. Stevens and Schulte (1979) presents results of anaerobic digestion of pig manure at temperatures of 22.5-40 °C. The used manure has a high COD/VS ratio of 1.9-2.1. Reported gas productions at different conditions differ between 0.29-0.68 m³ CH_4/kgVS. Based on the reported COD effluent values, again much lower gas production values are re-calculated, viz. 0.24-0.36 m³ CH_4/kgVS.

As the IPCC B_o default values, presented in Table 1, are for a large part based on the above cited references, re-estimation of the default B_o values should be considered.

Zeeman (1994) estimates the anaerobic biodegradability of swine manure to be 70% and that of dairy manure to be 50% of the total COD based on results of laboratory research (Zeeman, 1991 and Velsen, 1981). These biodegradability values are based on the highest removal efficiency during continuous experiments. Considering that 1g VS=1.4 g COD, this will result in a B_o value of 0.25 and 0.34 m³ CH_4/kgVS for dairy and pig manure, respectively.

The IPCC default values are estimated at 0.24 and 0.45 m³ CH_4/kgVS, respectively. Especially the latter is relatively high. Considering the above mentioned value of 1.4 for conversion of VS to COD, this would mean that 0.45/1.4/0.35 ●100%=92% of the influent COD of pig manure would be biodegradable.

Sensitivity analysis

Gerbens (1999) calculated 14.2 Tg global CH_4 emission per year for major contributors (dairy, non-dairy, buffalo and swine) of animal manure based on the IPCC defaults values and for assumed temperate climatic conditions in North America (NA), Western Europe (WE), Eastern Europe (EE), Oceania (OC), and Asia (AS) and warm climatic conditions in Latin America (LA), Africa (AF), Middle East (ME) and the Indian Subcontinent (IS). Considering the above suggested lower B_o value of 0.34 instead of the IPCC default value 0.45 m³/kg VS for pig slurry, the total global methane emission will become 13.1 Tg/year instead of 14.2 Tg/year. When the default B_o value for pig manure in developing countries is proportionally lowered to 0.22 m³ CH_4/kgVS instead of the IPCC default value of 0.29 m³ CH_4/kgVS, a global methane emission from animal manure of 12.6 instead of 14.2 Tg/year is arrived at.

Recommendations

The above discussions lead us to the following recommendations:

- Determination of the (corrected) COD/VS value for 'fresh' manure by reviewing literature for total COD, VS and VFA concentration (if available) and recalculating the default B_o values.
- Standardising the determination of B_o, including analysis of total COD, VFA and VS.
- Determination of the B_o values for different types of 'fresh' animal manure under standardised conditions.

(b) IPCC, Tier 2

B_o value for each representative animal type should defined. The IPCC Tier 2, includes a determination of the B_o value for each representative animal type defined. Country specific data should be used where feasible. Otherwise the default value (Tier 1) are to be used.

Recommendations

In order to be able to develop reliable country specific data for the B_o value, a standardised method for the determination of B_o is to be developed. A standardised method should include:

- Sampling method;
- Number of samples to be taken;
- Type of analysis to characterise the manure sample, and
- Procedure for the B_o determination.

2.1.2 Methane Conversion Factor (MCF)

Methane emissions from animal waste strongly depend on the specific manure management system applied and also on the conditions and the manner the system operates. The manure management systems as identified within the *IPCC Guidelines* are presented in Table 4.

TABLE 4

CHARACTERISTIC OF THE IPCC METHOD FOR IDENTIFIED MANURE MANAGEMENT SYSTEMS

Management system	Characteristics	Storage time
Pasture/range	The manure from pasture- and range-grazing animals is allowed to remain as it is, and is not handled at all.	
Daily Spread	Manure is collected in solid form by some means, such as scraping. The collected manure is applied to fields regularly.	
Solid Storage	Manure is collected in solid form by some means, such as scraping.	long period of time (months)
Drylot	In dry climates animals may be kept on unpaved feedlots where the manure is allowed to dry until it is periodically removed. Upon removal, the manure may be spread on the fields.	
Liquid/slurry	These systems are generally characterised by large concrete-lined tanks built into the ground	≥ 6 months
Anaerobic lagoon	Anaerobic lagoon systems are characterised by flush systems that use water to transport manure to the lagoons. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields	30 days to >200 days
Pit storage	Liquid swine manure may be stored in a pit while awaiting final disposal. The pits are often constructed beneath the swine building	two categories: <1 month > 1 month
Anaerobic Digester	Produce CH_4 gas for energy. The amount of CH_4 produced depends on the operating characteristics of the digester and the characteristics of the manure.	
Burned for Fuel	Manure is collected and dried in cakes and burned for heating or cooking. This system is common in Asia and the Far East. In India it is estimated that two-thirds of cattle manure is burned for fuel.	

The actual methane emission will not only depend on the system and the climatic conditions, but also on the manner of management. Moreover the climatic conditions are not always representative of the temperature conditions in the manure. The latter is especially the case when pit storages for pig manure are involved as these systems are constructed beneath the swines in the buildings. This means that the manure temperature will be determined by the climatic conditions in the stable more than by the conditions outside.

In order to identify possible errors in the estimated MCF default values for animal manure, it is necessary to investigate the major manure methane emitting management systems in more detail. As shown in Table 5, the wet manure systems (liquid/slurry tanks, pit storage and anaerobic lagoons) are the most important methane emitting manure management systems. All three systems can be considered as non-optimised anaerobic reactors, operated in a fed-batch mode. Fed-batch means that the storage/reactor is filled in time, until it is completely full.

After filling, the reactor is emptied leaving only some left over 'stored' manure (inoculum). The fraction of 'stored' manure which is left over after 'emptying' the storage, will, amongst others, largely determine how much methane will be produced during the filling period (Zeeman, 1991). If the storage could be completely emptied after filling, so that no methanogenic bacteria are left, methane emissions could be considerably reduced, unless very long storage times are applied. When a high fraction of inoculum is left, the methane emission will increase. Zeeman (1991 and 1994) assumes, on the basis of practical experience, that always *ca.*15 percent of the manure storage cannot be emptied, leaving a (methanogenic) inoculum in the storage. Especially when pig manure is used, solids will settle to the bottom of the storage, increasing the solids detention time as compared to the liquid detention time resulting in an even higher methane emission.

Default MCF values (*Anaerobic lagoons)*

The anaerobic lagoon is designed to have a longer SRT (sludge retention time) than HRT (hydraulic retention time), which can result in a high MCF value. When the SRT becomes infinite, the MCF will approach 100% irrespective of the temperature applied. The IPCC method assumes an MCF factor of 90%. The HRT in anaerobic lagoons can however vary between 30 and >200 days. It is not sure whether the high MCF values will always occur. At the lower HRT's also the SRT will decrease, resulting in lower MCF factor as compared to the factor of 90 percent as proposed by the *IPCC Guidelines* especially when low temperature conditions prevail. Zeeman (1994) calculates a MCF value of only *ca.* 50 percent, when a temperature of 10-15°C and a storage time as long as 360 days (HRT=SRT) prevails.

Sensitivity analysis

Gerbens (1999) calculated a *14.2 Tg* global CH_4 emission per year for major contributors (dairy, non-dairy, buffalo and swine) of animal manure based on the IPCC defaults MCF values and for assumed temperate climatic conditions in NA, WE, EE, OC and AS and warm climatic conditions in LA, AF, ME and IS. Considering default MCF values for anaerobic lagoons of 70% instead of 90 %, a global CH_4 emission from animal manure of *13.7* instead of 14.2 Tg/year was arrived at.

The MCF factor does not depend on the manure management system used, but also on the temperature of the stored manure, and the handling of the system. Table 5 provides the MCF values for the different systems at different temperature conditions as used in the *IPCC Guidelines.*

TABLE 5

METHANE CONVERSION FACTORS (PERCENTAGE) FOR DIFFERENT MANURE MANAGEMENT SYSTEMS AND CLIMATES FOR DAIRY CATTLE, FOR NON-DAIRY CATTLE AND FOR BUFFALO

Manure Management System MCFs for dairy cattle, for non-dairy cattle and for buffalo									
Climate	Lagoon	Liquid /slurry	Solid storage	Drylot	Pasture range	Daily Spread	Digester	Burned for fuel	Other
Cool	90	10	1	1	1	0	10	10	1
Temperate	90	35	1.5	1.5	2	0.5	10	10	1
Warm	90	65	2	5	2	1.0	10	10	1
Manure Management System MCFs for Swine									
Climate	Lagoon	Liquid /slurry	Solid storage	Drylot	Pit <1 month	Pit >1 month	Daily Spread	Digester	Other
Cool	90	10	1	1	5	10	0.1	10	1
Temperate	90	35	1.5	2	18	35	0.5	10	1
Warm	90	65	2	5	33	65	1	10	1
Source: IPCC 1995/1996									

Liquid/slurry tanks and pits

According to the *IPCC Guidelines* the liquid/slurry storage tank has a storage time ≥ 6 months. The default MCF factors chosen are 10, 35 and 65 percent for mean temperatures of 10-15 ^{o}C (low), 15-25^{o}C (temperate) and > 25°C (warm) respectively. The pits are divided into those with a storage capacity < 1 month and those with a storage capacity > than 1 month. The default MCF factors chosen are also 10, 35 and 65 % for mean temperature of 10-15^{o}C (low), 15-25 ^{o}C (temperate) and > 25°C (warm) respectively for >1 month storage capacity and 15, 18 and 33% for storage capacities of<1 month. Zeeman (1994) estimated some of these MCF values differently as presented in Table 6.

TABLE 6

COMPARISON BETWEEN IPCC DEFAULT MCF VALUES AND MCF VALUES AS OBSERVED BY ZEEMAN (1990)

Manure management Strategy	Climatic condition	MCF (%) (IPCC, 1997)	MCF (%) (Zeeman, 1994)
Liquid/slurry	Cool	10	39
	Temperate	35	45
	Warm	65	72
Pit < 1 month	Cool	5	0
	Temperate	18	0
	warm	33	30
Pit > 1 month	Cool	10	39
	Temperate	35	45
	Warm	65	72

For methane emissions calculated by Gerbens (1999), the use of MCF values as observed by Zeeman (1990), would result in a global CH_4 emission estimate of 16.3 Tg instead of 14.2 Tg. Therefore a significant (15%) increase is established by adapting the MCF values derived by Zeeman (1994).

Considerations

Zeeman (1994) calculated a higher MCF factor at low temperature conditions and a somewhat higher MCF value at median and high temperature conditions, considering 180 days storage time and 15 percent of the stored manure (inoculum) to be left over after emptying. When more or less manure is left over after digestion, methane emissions will considerably change. In countries with low temperature winters, no manure will be applied on the field during the winter period. Therefore before winter starts the manure storage will be emptied as much as possible provided that enough storage capacity is available. The emptying in summer will depend on the possibility to use the fertilisers on the fields. The emptying of manure tanks in warm climates will presumably be mainly controlled by the possibility to use the manure on the fields. It is very important to gain insight into the way of management of these systems in warm climate countries. When a large fraction of manure is left in the storage, it implies that the system is operated more as a CSTR (continuously stirred tank reactor) than a fed-batch system, then very high methane emissions can be expected, even in pit storages of less than 1 month.

Recommendations

As the way of management of the storage can influence the MCF factor substantially, it is recommended to collect more data on this item, especially for high temperature countries.

- Based on these data collection, the mean percentage of manure left over (=inoculation) after 'emptying' (use) is to be estimated.
- Default MCF values can be re-estimated based on the estimated percentages of inoculation, the defined storage period and the temperature conditions with the aid of model calculations (Zeeman, 1994).

Digesters

The *IPCC Guidelines* includes a MCF default value for anaerobic digesters of 10 percent. The gas collection, gas use, the gas flaring facilities and also the manner and period of storing digested manure will, however, to a large extent determine the actual methane emissions. Whether the above-mentioned facilities are included or not, this will largely depend on the scale in which digestion is performed. In principle, zero emissions could be achieved. It is therefore recommended to develop different default values depending on the type of facilities included. The following categories are recommended:

- presence of a gas collection system with a buffer capacity larger than the volume of daily gas production;
- presence of a gas flare for flaring excess gas, and
- presence of a gas tight cover for collecting and using the gas produced during the storage of digested manure. The best way is combining the gas collection system with the storage of the animal manure.

Zeeman (1994) calculated that when pig manure is digested in a CSTR at 30°C and 20 days digestion time, the controlled methane production is 18.4 m^3/ m^3, while additional 2.4 m^3/ m^3 is produced during storage under Dutch conditions.

Specifying the MCF values for digesters is also recommended because, with the now recommended MCF defaults values, it is suggested that controlled anaerobic digestion should always include a relatively high methane emission, which could prevent the implementation of the method. However as discussed above, anaerobic digesters can also be constructed in way that no or hardly any methane emission will occur. Moreover, when the use of gas for replacing fossil fuel or wood is included, the reduction in total global warming potential is substantial (Gerbens and Zeeman, 1999). Both aspects makes controlled anaerobic digestion a highly attractive method for reducing emissions of greenhouse gases (Gerbens and Zeeman, 1999).

3 CONCLUSIONS

- Manure will always contain a fraction of volatile fatty acids (VFA), which will result in an over estimation of the B_o; value when based on VS. B_o determination should, next to VS, include total COD and VFA analysis.
- Standardisation of the B_o determination, including sampling methods is recommended;
- The actual MCF factor will vary with the manure management system, the temperature of the stored manure, and the handling of the system. The mean percentage of manure left over (=inoculation) after 'emptying' (use) is of crucial importance;
- It is recommended to collect more data on percentage inoculation in storages and re-estimate default MCF values with the aid of model calculations;
- Specifying the MCF values for digesters is recommended because, with the now recommended MCF defaults values (10 percent), it is suggested that controlled anaerobic digestion should always include relatively high methane emissions, and
- Anaerobic digesters can be constructed such that no or hardly any methane emission will occur.

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