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Methane losses from floating gasholder type biogas plants in relation to global warming

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Methane losses from uncovered portion of cattle dung slurry in biogas plant of various capacities (3, 6, 9, and 85 m^3) are measured using closed chamber method. Measurements are conducted from January to December 2002 during a year. Mean methane flux from different exposed areas of a biogas plant of 3 m^3 capacity are: (i) Inlet/outlet pipes; 70 $g/m^2/d$, (ii) Around gasholder; 87 $g/m^2/d$, and (iii) Slurry tank; 41 $g/m^2/d$, and increased by 15-20 per cent with the increase in plant capacity to 85 m^3. Seasonal variation of slurry temperature strongly affects the methane emission. Emission rates during the summer are found to be high (125, 179, 230 and 230 $g/m^2/d$, respectively, from the holder side of 3, 6, 9, and 85 m^3) at slurry temperatures near optimum mesophilic range (32° C during June) and drop down considerably (68 to 79 per cent) during winter at slurry temperatures in the lower psychrophilic range (13°C in December). The correlation coefficient between the CH_4 flux and the slurry temperature is found to be positive (between 0.90 and 0.96) and significant.

Keywords: Biogas plant, Floating gasholder, Global warming, Greenhouse gases, Methane losses, Slurry pit

IPC: Int Cl.^{7}: G 01 W 1/100, C 01 B 3/02

Introduction

Methane is one of the principal greenhouse gas and has been estimated to account for 15-20 per cent of current radiative forcing[1]. The increase of methane in the atmosphere contributes to global warming and affects the chemical changes in the atmosphere[2-4]. Current atmospheric concentration of CH_4 is around 1.75 ppmV, but it is predicted that up to the year 2100, CH_4 level may rise to 3-4 ppmV, which may have a significant effect on global warming[5]. Conventional biogas plants are known to emit certain amount of CH_4 in the form of biogas[6,7], from the uncovered portion of biogas slurry. Methane constitutes 60-70 per cent of the biogas under normal working conditions[8] and their loss has been a matter of great concern for the environmentalists.

In India, biogas technology has been in use for nearly one century[9]. Several models of biogas plant have been developed by various institutions and organizations, solving specific problems[10]. Floating gasholder type biogas model (KVIC) is one of the widely accepted models in the country. At present, more than 3 m family size biogas plants and 4000 large capacity institutional/community biogas plants have been installed throughout the country under the National Programme on Biogas Development[11]. This covered only one-fourth of the estimated potential of 12 m biogas plants installation in India. In future the number of biogas plants is going to rise considerably, thereby increasing the contribution of CH_4 to the atmosphere. The study presents the quantitative estimates of CH_4 from the uncovered slurries of the floating gas holder type biogas plants.

Material and Methods

Experimental Plants

The plants under the investigation were floating gasholder type biogas plants of the capacities: 3 m^3 (located near Inter State Bus Terminus, Delhi), 6 m^3 (Noonagar Village, UP), 9 m^3 (IARI, Delhi) and 85 m^3 (Masudpur, Delhi). Except the 9 m^3 biogas plant which was an Indian Agricultural Research Institute (IARI) model, all the other plants were of the Khadi and Village Industries Commission (KVIC) model. Cattle dung was the feedstock in all the plants. The main feature of the floating gasholder type biogas plant is a well type digester and a mild steel gasholder immersed in the slurry contained in the digester.

Gas Sample Collection and Analysis

Table 1—Methane flux from uncovered sites of floating gasholder type biogas plant

Months	Temp, °C A(S)	Inlet/outlet ($g/m^2/d$)				Holder side ($g/m^2/d$)				Slurry pit ($g/m^2/d$)	
		3 m^3	6 m^3	9 m^3	85m^3	3 m^3	6m^3	9m^3	85m^3	3 m^3	85m^3
Jan	19 (13)	31	27	42	39	43	56	86	106	12	24
Feb	25(17)	40	63	53	61	51	63	93	163	20	35
Mar	29(25)	58	85	67	90	76	99	101	185	23	47
Apr	30(27)	71	94	85	112	93	121	134	200	25	61
May	34(31)	93	118	103	130	119	158	196	211	66	93
Jun	35(32)	117	132	125	144	125	179	230	230	73	111
Jul	33(32)	112	155	117	160	136	175	221	209	70	95
Aug	33(31)	96	120	109	119	117	136	213	206	68	75
Sep	32(30)	81	107	95	116	93	112	187	203	52	66
Oct	31(28)	65	86	73	95	88	90	143	175	45	52
Nov	28(24)	51	66	62	71	60	72	102	154	27	46
Dec	18(13)	26	40	39	45	39	45	73	68	15	23
Mean	30(25)	70	91	81	99	87	109	148	176	41	61

A-Ambient; S-Slurry

Gas samples were collected from the different uncovered slurry sites: (i) Outlet/inlet pipes, (ii) Space around the floating gasholder, and (iii) Outlet slurry tank of the plants by using closed chamber techniques[12]. Cylindrical PVC chamber (5 cm diam x 55 cm ht) was used in slurries around the gas holder and floatable iron sheet chamber (25 cm diam x 30 cm ht) was used to collect samples from the slurry pits. The chamber was placed in the slurry, maintaining a fixed headspace. Gas samples were drawn, using airtight syringe (20 mL) at intervals of 0, 5, and 10 min, respectively. By flushing the syringe, two to three times the air inside the chamber was thoroughly mixed while drawing the gas samples. Methane concentration in the gas samples was quantified by using a gas chromatograph (Shimadzu, GC-8A) fitted with Flame Ionization Detector (FID) and Porapak Q column. The column, detector, and injector were maintained at 50, 130, and 120°C, respectively. Carrier gas was nitrogen with a flow rate of 20 to 25 mL/min. Hydrogen was chosen as the fuel gas and zero air as the supporting gas having the flow rates of 25 and 250 mL/min, respectively. The concentration of CH_4 in a sample was determined by calculating the known amounts of CH_4 under the same set of conditions. Primary standard used was 14.04 ppmV CH_4 in nitrogen for methane, which was procured from National Physical Laboratory, New Delhi.

The methane flux (F) was calculated using the following equation[6]:

$$F = [(C_t - C_o)/t] \times H \times 42.857 \text{ mg/m}^2\text{/h},$$

where t is time (min), C_o is the initial concentration of CH_4 (ppmV), C_t is the final concentration of CH_4 (ppmV), and H is height of headspace (m).

The ambient and slurry temperatures of the biogas plant were recorded 15 cm below the surface, by using an ordinary mercury thermometer at the time of sampling. All the samples were collected in triplicate from each of the uncovered sites of the plants, once a day between 11.00 and 11.30 h at weekly intervals and the average is reported.

Results and Discussion

Table 2 ─Dimension of uncovered slurry and average methane emission

Plant	Inlet+Outlet		Holder side		Slurry pit		Total CH$_4$	
	Dimension (m^2)	CH$_4$ (g/d)	Dimension (m^2 x m)	CH$_4$ (g/d)	Dimension (m^2 x m)	CH$_4$ (g/d)	CH$_4$ (g/d)	CH$_4$ (kg/y)
3 m^3 KVIC	0.0076 x 2	1.06	0.25 x 0.95	21.52	4 x 1	165.2	187.70	68.53
6 m^3 KVIC	0.0076 x 2	1.38	0.66 x 0.95	71.82	-	-	73.20	26.71
9 m^3 IARI	0.0076 x 1	0.62	0.62 x 1.20	97.84	-	-	98.46	35.93
85m^3 KVIC	0.0076 x 2	1.50	1.63 x 1.20	286.6	30 x 1	1820	2108.10	769.45

The data on methane losses from the slurries in the exposed areas of the biogas plants show that the rate of methane flux increases with increase in plant capacities (Table 1). This increase in CH$_4$ emission was attributed to the increase in dimension of the slurry (surface area and the column of slurry underlying the area). The dimension of the uncovered slurry around the floating holder increase from (0.25 m^2 surface area x 0.95 m ht) in a 3 m^3 KVIC biogas plant to (1.63 m^2 surface area x 1.20 m ht) in a 85 m^3 plant (Table 2). The mean CH$_4$ flux from the gasholder increases in the larger capacity plants (87 g/m^2/d in 3 m^3, 109 g/m^2/d in 6 m^3, 148 g/m^2/d in 9 m^3, and 176 g/m^2/d in 85 m^3). Corresponding total methane emitted per plant from the four units was 63.96, 73.17, 98.46 and 286.6 g/d, respectively. With the increase in plant capacity the amount of outlet slurry dumped for drying also increased. As the depth of the slurry pit was prescribed normally less than 1 m to facilitate evaporation and easy handling of manure, there was considerable increase in the surface area of pits in larger plants. The surface area of the slurry pit increases from 4 m^2 in a 3 m^3 plant to around 30 m^2 in a 85 m^3 plant, contributing 0.165 and 1.82 kg CH$_4$/d, respectively, to the atmosphere. The loss of CH$_4$ in terms of biogas from each m^3 of the two slurry pit would be 0.096 and 0.141 m^3/d (assuming that, CH$_4$ constitutes 60 per cent v/v in biogas), which is equivalent to 24.1 and 35.3 per cent, respectively, against the biogas production potential of digester slurry (0.4 biogas m^3/d/m^3 digester).

The higher emission rates from the slurry pit might be due to increase in content of digestible organic carbon in the outlet slurry, supporting active methanogenesis. As the plants were not overloaded, this possibly may be due to reduction of Hydraulic Retention Time (HRT*)* of the plants. HRT for digester operating in countries of tropical region like, India is usually taken as 45-50 d. This is chosen as to achieve at least 70-80 per cent digestion[13]. Prolonged operation of plants without cleaning faced problems like, siltation and formation of solids lumps on the periphery of the digesters, thereby developing channel like cavity between the inlet and outlet, reducing the effective volume of the digester and HRT. It is desirable to empty the digester once every 5-6 y (ref. 14, 15). All the plants under investigation were in continous operation for more than 5 y, at the time of the study. In the plants of capacities of 6 and 9 m^3 the outlet slurry was directly led to the agricultural fields and no slurry pit was maintained.

In all the plants the rates of methane emission from inlet/outlet were slightly higher than the slurry pit but were consistently lower than the flux from the areas around the gasholder. The average methane fluxes recorded from the inlet/outlet, gasholder side and slurry pit of a 3 m^3 plant were 70, 87, and 41 g/m^2/d, which correspond to emission of 1.06, 21.52 and 165.28 g/d CH$_4$, respectively. Due to larger surface area of emission the main contribution of CH$_4$ (>80 per cent) comes from the slurry pit, followed by gasholder side, which emits around 10 per cent of the total CH$_4$ losses to atmosphere. The contribution of CH$_4$ from the inlet and outlet pipes was comparatively insignificant, ranging between 1.24 and 1.50 g/d (around 1 per cent of the total emission) in various capacity plants, owing to the lesser surface area it has (0.015 m^2), despite their having higher flux to that of the slurry pit. In the IARI model plant, a notch in the top of the digester wall formed the outlet and no separate record was made for outlet.

Although the amount of CH$_4$ lost from all the points of the plants, under investigation, was found different, they follow a similar pattern of rise and fall of fluxes corresponding to changes in temperature at different periods of the year. The slurry temperature recorded during the study ranged between 13^o (January and

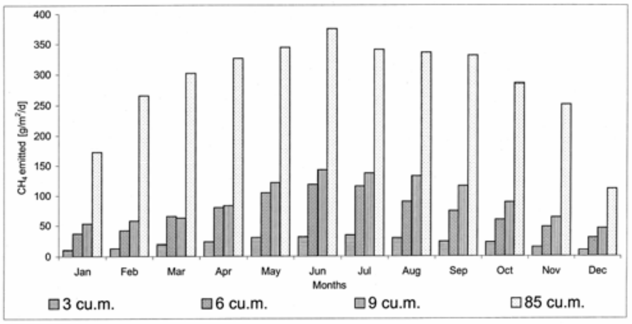

Figure 1─Seasonal variation of methane emission from gasholder side of biogas plants

December) and 32°C (June and July). Correspondingly the average CH_4 fluxes from the exposed areas of holder sides of all the plants showed seasonal variations, 39 to 136 g/m^2/d (3 m^3), 45 and 179 g/m^2/d (6 m^3), 73 and 230 g/m^2/d (9 m^3) and 68 and 230 g/m^2/d (85 m^3) (Figure 1). Emission rates from all the emitting points were recorded high during the summer months (highest in June and July) when the slurry temperatures reach near optimum mesophilic range. With the onset of winter and rapid fall in ambient temperature, CH_4 fluxes were considerably reduced. All the plants were found to work in the lower psychrophilic range (below 15°C) during January and December. Methane emissions were reduced to about 68 to 79 per cent, in December against the emission rate in the month of June. Biomethanation is strongly influenced by the temperature. An important characteristic of anaerobic bacteria is that their decay rate is very slow below 15°C (ref. 16). In the mesophilic range the bacterial activity and growth decreased by one-half for each 10° drop below 35°C. At 10°C, it is more or less stopped[17]. The correlation coefficient between the slurry temperature and the methane flux from the inlet, gasholder and outlet of the plants were positive (ranging between 0.90 and 0.96) and significant.

Conclusions

Conventional biogas plants installed to generate CH_4 for fuel energy are considered to be a source of CH_4, contributing to the atmospheric methane budget. The methane emission increases with the increase in plant capacity, varying between 68.34 to 271.12 kg/y from a 3 and 85 m^3 biogas plant. But the overall per day CH_4 contribution from this source would be directly related to the total amount of biogas generated per day in the country, irrespective of plant sizes. Within a biogas unit, the main contributor of CH_4 is from the slurry pit (>80 per cent), due to its larger emitting surface area. The uncovered slurry around the gasholder and the inlet/outlet pipes, contributes around 10 and 1 per cent, respectively, of the total CH_4 losses. Seasonal variation of temperature strongly affects the CH_4 emission from the biogas plants. Based on these emission rates the contribution of biogas plants installed, in India, towards the annual methane budget is estimated to be approximately 0.25 Tg.

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