

# The effect of turning frequency on methane generation during composting of anaerobic digestion material

*Ảnh hưởng của sự đảo trộn đến quá trình sinh khí mê tan trong đống ủ phân compost của chất thải từ hầm ủ biogas*

Research article

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Methane (CH<sub>4</sub>) is included in the direct greenhouse gases listed in the Kyoto protocol. The composting of anaerobic digestion (henceforth AD) material is a source of CH<sub>4</sub>. CH<sub>4</sub> is the major contributor to overall CO<sub>2</sub> emissions. Therefore, it is important to know the formation of this gas from different stages and substrates of the composting process. This study investigated CH<sub>4</sub>, CO<sub>2</sub> and O<sub>2</sub> profiles in two open-windrows in composting plants treating AD material. One composting windrow was turned one a week; whereas another was turned twice a week using a special windrow turner. To assess the gaseous formation in the composting windrows, CH<sub>4</sub>, CO<sub>2</sub> and O<sub>2</sub> volume concentrations were measured at different depths. Active aeration has been considered as a method to reduce CH<sub>4</sub> generation during composting. However, our results showed that frequent turned windrow generated more CH<sub>4</sub> than less turned windrow. The highest CH<sub>4</sub> concentrations were found at a depth of 1 m, and were 45% and 37% for 2 times a week turned windrow and 1 time a week turned windrow respectively. Gas concentrations of CH<sub>4</sub>, O<sub>2</sub> and CO<sub>2</sub> in both windrows differed. Concentrations of CO<sub>2</sub> and CH<sub>4</sub> increased with depth, whereas concentration of O<sub>2</sub> decreased from the surface to the lowest point. The O<sub>2</sub> and CO<sub>2</sub> are important factors in determining whether the windrows are anaerobic or aerobic.

*Khí mê tan (CH<sub>4</sub>) là một trong những khí nhà kính được liệt kê trong nghị định thư Kyoto. Quá trình ủ phân compost từ các chất thải của hầm ủ biogas là nguồn phát sinh loại khí này. Khí mê tan đóng góp chủ yếu trong tổng lượng khí nhà kính phát thải vào khí quyển. Do đó, những hiểu biết về quá trình hình thành loại khí này trong các giai đoạn khác nhau của quá trình ủ phân compost từ chất thải hầm ủ biogas là rất quan trọng. Nghiên cứu này tìm hiểu sự phát thải khí CH<sub>4</sub>, CO<sub>2</sub> và O<sub>2</sub> trong 2 luống ủ ngoài trời tại các nhà máy xử lý rác thải hữu cơ bằng phương pháp kỵ khí. Luống ủ 1 được đảo trộn một lần một tuần trong khi luống ủ số 2 được đảo trộn 2 lần 1 tuần. Để đo đặc lượng khí phát thải từ các luống ủ phân compost, nồng độ các khí CH<sub>4</sub>, CO<sub>2</sub> và O<sub>2</sub> được đo ở các độ sâu khác nhau. Việc cung cấp khí oxy được coi như là một biện pháp để làm giảm sự hình thành khí mê tan. Tuy nhiên, kết quả đo đạc của chúng tôi chứng minh rằng việc đảo trộn thường xuyên phát thải nhiều khí mê tan hơn ít đảo trộn. Nồng độ khí mê tan cao nhất 45% và 37% đo được ở khoảng cách 1m từ bề mặt đối với luống ủ đảo trộn hai lần và một lần. Nồng độ các khí CH<sub>4</sub>, CO<sub>2</sub> và O<sub>2</sub> khác nhau ở hai luống trong thí nghiệm. Nồng độ khí CH<sub>4</sub> và CO<sub>2</sub> tăng theo độ sâu, trong khi O<sub>2</sub> giảm theo độ sâu. Nồng độ khí CO<sub>2</sub> và O<sub>2</sub> đóng vai trò quyết định luống ủ được cung cấp đủ oxy cho quá trình phân hủy hiếu khí hay không.*

**Keywords:** greenhouse gas, emissions, composting, windrows, organic waste, methane

## 1. Introduction

Anaerobic digestion (AD) material is treated either by active aeration composting or by a combination of active aeration and open composting windrow (Mata-Alvarez *et al.*, 2000). Aeration is an important parameter in controlling the composting process (de Guardia *et al.*, 2008; Maeda *et al.*, 2010). Microbes are supplied oxygen for hydrocarbon degradation and elevate the compost temperature to the thermophilic range. Aeration is a key element in controlling the temperature regime and thus, the performance of any composting operation (Beck-Friis *et al.*, 2000; Thompson *et al.*, 2004; Fukumoto *et al.*, 2003). Under aerobic conditions, microbes can rapidly degrade the available hydrocarbons releasing large amounts of energy to elevate the compost temperature to the thermophilic range.

It is known that increasing the oxygen supply will reduce the methane formation and emissions (Möller & Sommer, 2000). During the composting process, the production of methane is strongly dependent on process management. Methane is a main product of anaerobic methanogenesis, while carbon dioxide is a main product of both aerobic and anaerobic processes (Hellebrand, 1998). Hence, substrate quality and quantity, its aeration rate, and the duration of composting influence these gas productions. (Beck-Friis *et al.*, 2000; He *et al.*, 2000; Möller & Sommer, 2000; Hao *et al.*, 2001; Clemens & Cuhls, 2003; Fukumoto *et al.*, 2003; Thompson *et al.*, 2004). Only a few studies regarding direct gaseous formation in the anaerobic digestion material composting are available.

The aim of this research is to examine the concentration of CH<sub>4</sub>, CO<sub>2</sub> and O<sub>2</sub> in two composting windrows from AD material. Furthermore, temperature, moisture content and oDM were measured during the study. Investigations were undertaken at a mechanical biological treatment plant in Germany treating biowaste and AD material.

## 2. Materials and methods

### 2.1. Site description and compost system

The primary objective was to measure and analyze the concentrations of CH<sub>4</sub>, CO<sub>2</sub>, N<sub>2</sub>O and O<sub>2</sub> in two different windrows using different composting management. One composting windrow was turned one a week; whereas another was turned twice a week using a special windrow turner. The composting process was limited to 10 weeks. The study was conducted at a mechanical biological treatment (MBT) plant in Germany. All of the incoming biowaste enters the continuous anaerobic digestion system. The MBT plant consists of one wet fermenter. The biowaste is first shredded and pressed to dry and wet fractions. The wet fraction is then pumped into a vertical fermenter, where temperature is maintained at thermophilic conditions (55°C). The hydraulic retention time is about 20 days. Feed is added to the fermenter at regular intervals. The digestate is separated into a solid and a liquid fraction by a decanter. The liquid fraction is recirculated into the process. The excess liquid is transport-

ed to farms and used as liquid fertilizer. The solid fraction is mixed with dry fraction and aerated in 14 days in an intensive composting tunnel without turning. Then, the material is piled up in small triangular windrows placed on a floor and is composted for another 35 days.

In the study, the gases (CH<sub>4</sub>, CO<sub>2</sub> and O<sub>2</sub>) were studied in the small triangular windrow. To conduct the research, the material aerated in the composting tunnel was arranged in triangular windrows, each 25m long, 6m wide (on the ground) and 2m high. The material was placed on a concrete floor. The composting material was AD material (> 100mm, 49% DM and 23.7% oDM).

The greenhouse gas concentrations in each windrow were measured every week. In addition, composting material was sampled and analyzed DM and oDM in the laboratory. After 10 weeks, the composting material was sieved (15mm) by a machine (Doppstadt-Sieb). The small fraction was collected for analyzing DM and oDM. In all, ten measurements were taken placed in the study.

### 2.2. Pore gas measurements

Gas concentrations in both windrows were analyzed. Three gradients were sampled in the windrow. At each sampling point, a gas probe was drilled into the windrow to a depth of 0.2, 0.4, 0.6, 0.8 and 1 m. Gas from the pore space was sucked into an infrared analyzer by a pump to detect CH<sub>4</sub>, CO<sub>2</sub> and O<sub>2</sub>. As a control, gas was sampled using 20 ml evacuated headspace vials. These were subsequently analyzed for CH<sub>4</sub> in the laboratory at the University of Bonn using Gas chromatography (GC) with Electron Capture Detector and Flame Ionization Detector (ECD/FID), (The Shimadzu Gas Chromatograph Mass Spectrometer GCMS-QP2010).

### 2.3. Temperature and moisture content measurements

The temperature was recorded every day. Six gradients were observed in the windrow. At each sampling point, a temperature probe was drilled into the windrow to a depth of 0.3 and 1m. The moisture content was determined by drying the samples at 105°C until the weight was unvarying. The percentage of moisture content was calculated in relation to the initial weight.

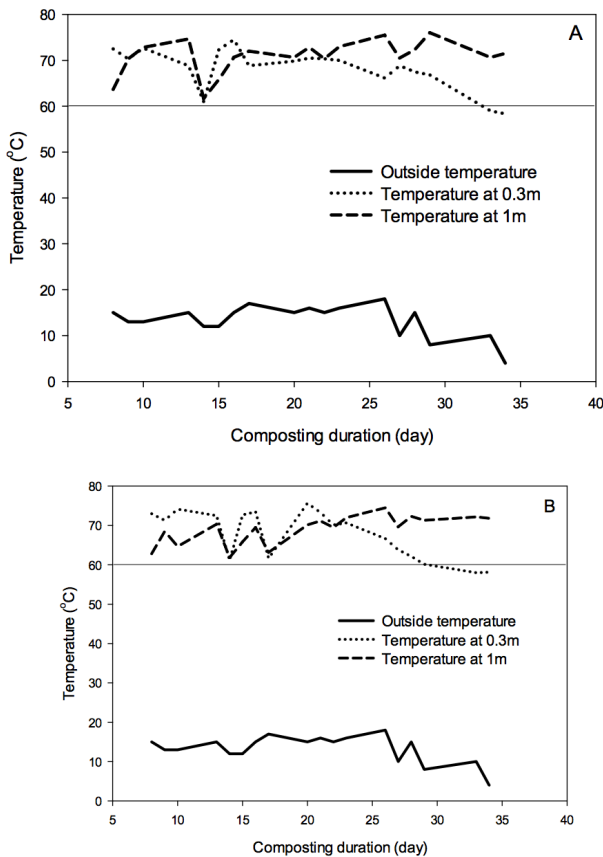
## 3. Results and discussion

### 3.1. Trend of temperature and moisture content

High temperatures (Fig. 1A and B) characterized in both studied windrows. After 7 days, the temperatures were above 60°C and remained during 30 days. The difference in temperature regimes between two windrows was insignificant. The temperature at 0.3 and 1 m depth were similar over the first 25 days. From the day 25 onward, significant temperature differences (ca. 10°C) occurred at depth 0.3 m and 1 m. Figure 1 also documents that the temperature reached maximum temperature 75°C in both wind-

rows in 26 days. After 35 days composting, a decrease in temperature without marked differences between windrow 1 and 2 was recorded.

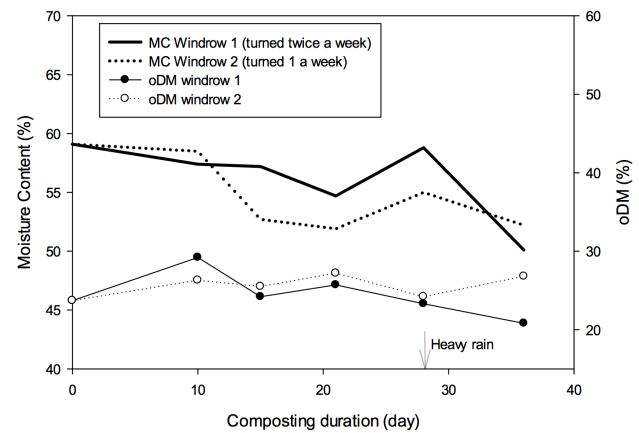
At the start of the study, water content (WC) was nearly 60%. WC decreased gradually to the value of 50% in both windrows. The WC of windrow 1, which was turned 2 times a week were rather higher than the windrow 2 turned 1 a week. During the study, the rainfall occurred; therefore, the windrow 1 was wetter due to the absorption of precipitation after turning. A higher moisture content leads to higher GHG emissions because it creates anaerobic conditions (Tamura & Osada, 2006).



**Figure 1: Temperature during the composting process. (A) Windrow 1 (turned twice a week). (B) Windrow 2 (turned 1 a week), measured a depth of 30 cm (dotted lines) and 1 m (dashed lines)**

Dry organic matter (oDM) decreased lightly during the 35 day composting from initial values of 29% to 20% in the windrow 1 (Fig. 2). A significant difference in the oDM content (9%) between the windrow 1 and 2 occurred at the day 35. Tendency, frequent turning reduced oDM due

to water evaporation and N loss. This result was in line with results from previous studies demonstrating the influence of windrow turning on water evaporation and organic material degradation (Szanto *et al.*, 2007; Ahn *et al.*, 2011).

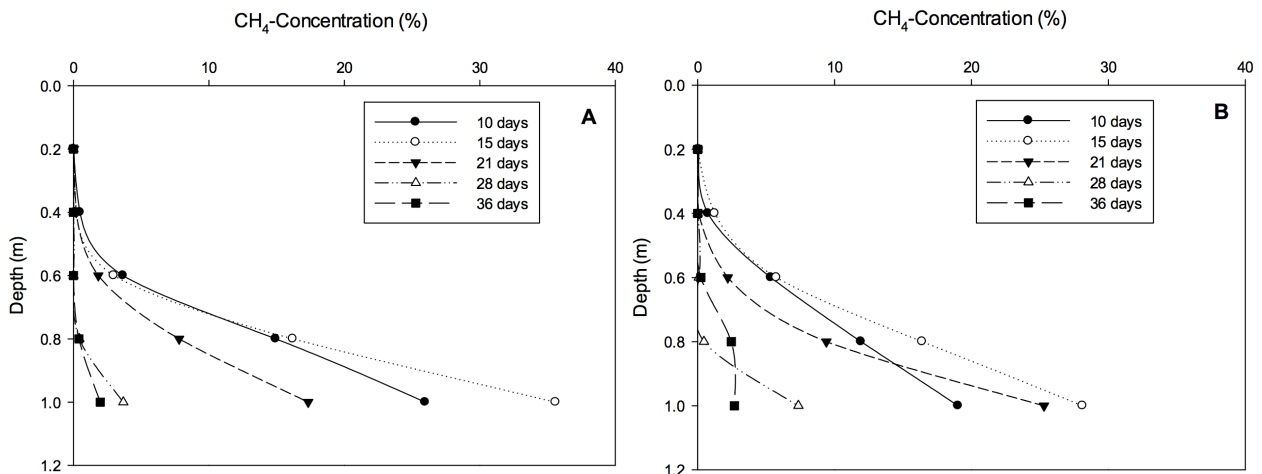


**Figure 2: Moisture content and oDM during composting treatment**

### 3.2. Gas phase concentration in the composting windrow

CH<sub>4</sub> concentration in pores of both windrows increased significantly from 0.2 to 1 m (Fig. 3). The highest CH<sub>4</sub> concentrations were 35% for windrow 1 and 27% for windrow 2. The high concentration of CH<sub>4</sub> found in the study was similar to those reported by (Beck-Friis *et al.*, 2000; Georgaki *et al.*, 2009; Ahn *et al.*, 2011). The generation patterns of CH<sub>4</sub> in the study resembled those reported by other works (Beck-Friis *et al.*, 2000; Georgaki *et al.*, 2009).

The maximum value of CH<sub>4</sub> concentration appeared on the tenth day, reaching 35% and 27% for windrow 1 and 2 respectively. The high CH<sub>4</sub> generation demonstrated the absence of oxygen and the involvement of anoxic/anaerobic micro-organisms (He *et al.*, 2000). CH<sub>4</sub> concentrations were high in both windrows during the first days and reduced significantly to the last day. Higher CH<sub>4</sub> generation occurred in the windrow 1 compared to windrow 2. The higher CH<sub>4</sub> generation in the 2 times turned windrow on the first days could be explained by the fact that CH<sub>4</sub> was produced through degradation of organic substances and organic acids in anaerobic conditions (Fukumoto *et al.*, 2003; Jiang *et al.*, 2010).

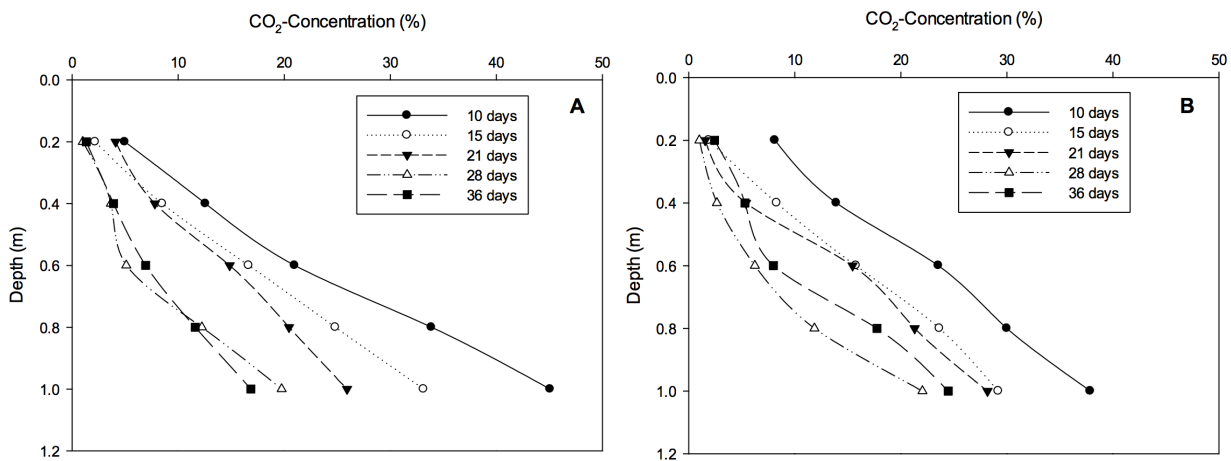


**Figure 3: CH<sub>4</sub> concentration in the windrows. (A) windrow 1 (turned twice a week). (B) windrow 2 (turned 1 a week), measured over the course of maturation of the composting the compost windrows**

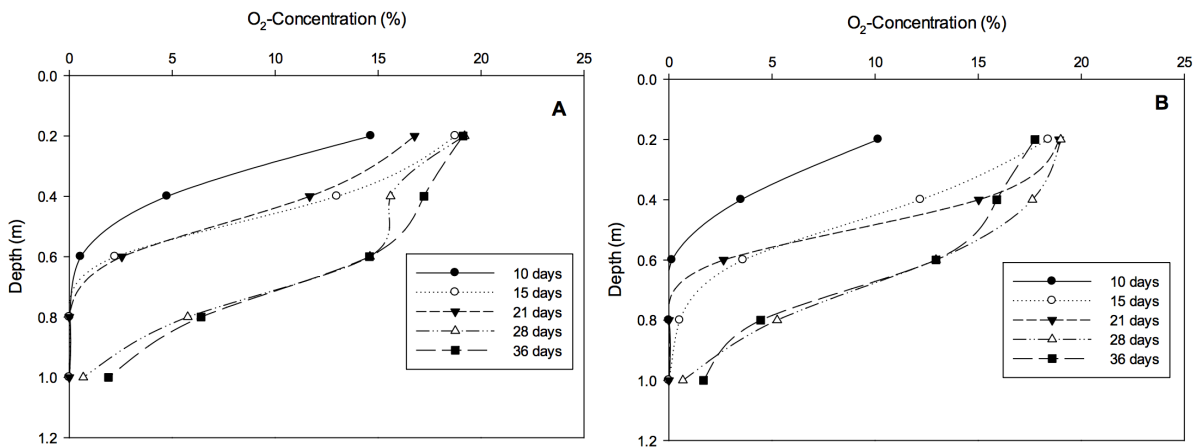
As can be seen in Fig. 4, CO<sub>2</sub> decreased with depth. At 1m depth, CO<sub>2</sub> concentrations were 45% and 38% in the windrow 1 and 2 respectively. The CO<sub>2</sub> generation more than 30% in both two windrows from day 10 to day 15. There were significant differences in CO<sub>2</sub> generation between the windrow 1 and 2 from the first 21 days during the composting. Gas generations were high in the early stage of composting. Higher CO<sub>2</sub> generation occurred in the windrow 1 compared to windrow 2. CO<sub>2</sub> concentrations were decreased from 45% to 15% and from 38% to 20% in the windrow 1 and 2 respectively at the end of the composting.

The generation rates mainly depended on the turning frequency, and as the frequent turning was increased, the level of CO<sub>2</sub> generation increased.

The O<sub>2</sub> concentration decreased significantly from 0.2 to 1m in both windrows (Fig. 5). The decrease of O<sub>2</sub> from the surface to the lowest point was due to biological activity that consumed O<sub>2</sub>. Our results are also consistent with the conclusions of (Xu et al., 2007). The highest O<sub>2</sub> concentration was at 0.2m and the lowest at 1m.



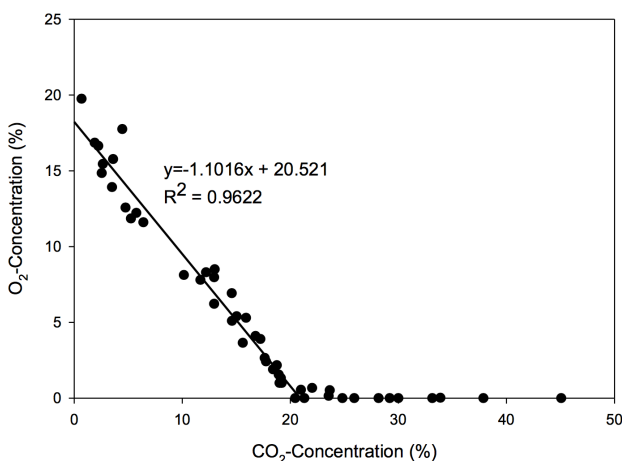
**Figure 4: CO<sub>2</sub> concentration in the windrows. (A) windrow 1 (turned twice a week). (B) windrow 2 (turned 1 a week), measured over the course of maturation of the composting the compost windrows**



**Figure 5: O<sub>2</sub> concentration in the windrows. (A) windrow 1 (turned twice a week). (B) windrow 2 (turned 1 a week), measured over the course of maturation of the composting the compost windrows**

### 3.3. Correlation of O<sub>2</sub> and CO<sub>2</sub> in the composting windrows

In the windrows, the O<sub>2</sub> and CO<sub>2</sub> concentrations (%) were negatively correlated (Fig. 6). An increase in CO<sub>2</sub> concentration led to a decrease in O<sub>2</sub> concentration and vice versa. This result is in line with (Sommer et al., 2004; Thompson et al., 2004 and Park et al., 2011). When CO<sub>2</sub> concentrations were above 20%, O<sub>2</sub> concentrations dropped to 0%. High O<sub>2</sub> and CO<sub>2</sub> concentrations in the composting windrow are evidence of aerobic decomposition (Hao et al., 2001). The decomposition of organic material with the presence of O<sub>2</sub> produces CO<sub>2</sub> and H<sub>2</sub>O, whereas the decomposition under anaerobic conditions produces CH<sub>4</sub> and CO<sub>2</sub>. Although, concentration of O<sub>2</sub> was nil, the degradation processes in windrow still seemed to be aerobic due to high concentrations of CO<sub>2</sub> (up to 20%). O<sub>2</sub> enter at the sides of the windrow, but only O<sub>2</sub> is consumed and transformed into CO<sub>2</sub> via respiration. Theoretically, a windrow with a CO<sub>2</sub> concentration of 20% could be still aerobic. Low concentration of O<sub>2</sub> but high concentration of CO<sub>2</sub> indicated that a chimney effect had developed in the windrow due to the convective transportation of gases.



**Figure 6: Concentration of O<sub>2</sub> and CO<sub>2</sub> in windrows**

### 4. Conclusions

The effects of turning frequency and moisture content on the generations of CH<sub>4</sub>, CO<sub>2</sub> and O<sub>2</sub> during composting of anaerobic digestion material were investigated in this study. The results of this investigation have shown that there were differences in the generation of gases from anaerobic digestion material which are dependent on one or two times turning frequency a week. Methane was produced more in the frequent turned windrow during the first days.

CH<sub>4</sub>, CO<sub>2</sub> and O<sub>2</sub> profiles in open-windrows differed. CH<sub>4</sub> and CO<sub>2</sub> concentrations in the windrow increased with depth; whereas, O<sub>2</sub> decreased. CH<sub>4</sub> was produced at high rate (>15 %) in the center of the windrows during the first 3 weeks. Production of CH<sub>4</sub> was low at the surface layers (0.3 m depth) due to O<sub>2</sub> availability. At 1 m depth, CH<sub>4</sub> and CO<sub>2</sub> were high at day 10 and decreased during the composting. Lower oxygen concentration caused higher methane generation. The moisture content and oDM reduced during the composting period, but not significantly.

Analyzing O<sub>2</sub> concentration alone is not enough to determine whether the windrow is aerobic or anaerobic. When O<sub>2</sub> and CO<sub>2</sub> concentration were 0% and 20% respectively, it was still aerobic in the windrow (CH<sub>4</sub> concentration was 0%).

### 5. References

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