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Development of Laser Scanning Method for Estimation of Spatial Distribution of Methane Emission in A Landfill

by

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Abstract

We proposed a method, named Laser Method which is used Laser Methane Detector (LMD) as a detector of ambient methane. This method is divided into three: hanged-LMD, held-LMD, and Laser Scanning (LS) Method and was used in two studies: lab scale and field study. The aims of these studies are The objectives of these studies are to describe methane concentrations (underground and ambient) and flux profile from different flow rates, wind speed, and cover utilization; to perceive the influence of wind speed and cover utilization of LMD in ambient methane concentrations measurements; to cognize the relationship between ambient methane concentrations and methane flux; to estimate methane emissions from the relationships; and to describe spatial distribution from methane emission estimation.

These studies indicate that ambient methane concentration and methane flux has a positive correlation and the correlation equation may be used to estimate methane emissions from landfill and the spatial distribution of estimation could be described. Wind and cover utilization have influence in these studies. In lab scale study, highest wind speed yielded lowest concentration. Moreover, measurements with using a cover become more precise than without using a cover. The cover could prevent the measurement from wind influence and outside interference.

Keywords: Methane, Landfill, Scanning method, Laser methane detector (LMD), Ambient methane concentrations, Methane flux, Underground methane concentrations

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1. Introduction

Methane is a major anthropogenic greenhouse gas second only to carbon dioxide in its effect on climate. It has a higher global warming potential than carbon dioxide, about 34 times over a 100-year time horizon, but a shorter atmospheric lifetime. Moreover, since the preindustrial period, the atmospheric concentration of methane has increased from approximately 722 ppb up to a global average of 1893 ppb till 2013[1)].

Methane is released through a variety of human activities, including landfill decomposition, agriculture (ruminant animal digestion, manure management and rice production), natural gas and petroleum systems (production, processing, transmission and distribution), coal mining, biomass burning and wastewater treatment. These sources account for approximately 70% of global methane emissions. The remaining 30% is released by natural sources, including wetlands, gas hydrates and permafrost, termites, oceans, freshwater bodies, non-wetland soils and wildfires[2)]. Landfills containing organic wastes produce biogas, consisting primarily of methane and carbon dioxide, and have been found to be a significant source of methane. Worldwide, the estimated emission from the waste sector accounted for 18% of global anthropogenic emissions of methane in 2004[3,4)]. By volume, landfill biogas typically contains 40% to 60% methane and 40% to 60% carbon dioxide[5)]. Landfills and open garbage dumps are full of organic wastes. Burial of these wastes creates anaerobic conditions, which favour methane generation.

As recognition of global climate change has increased, the contribution of landfill gas emissions to anthropogenic greenhouse effects has been taken into consideration, and in many countries landfill gas extraction and utilization plants have been made mandatory at all new waste disposal sites[4)]. However, in developing countries, most landfill sites are open dumps that receive municipal solid wastes with high methane generation potential, and no regulations to cover landfill gas emissions[6)].

In addition, methane poses an explosion hazard between its lower and upper explosive limits of 5% and 15% by volume in air[5)]. Because its concentration within a landfill is typically around 50%, it is unlikely to explode within the landfill boundaries. Although oxygen is absent under the conditions that produce methane, there is enough at the surface of the landfill to support an explosion, although the methane usually diffuses into the ambient air at concentrations below the lower explosive limit.

Indonesia—a developing country in the tropics—has many landfills; most of them open dumps, with no monitoring of gases. In the absence of monitoring, explosions killed 141 people at Leuwigajah landfill, in Bandung, West Java, in 2005[7)], and injured two people at Denpasar landfill, in Bali, in 2012[8)].

Several methods are used to measure landfill methane emissions. The flux chamber method is most commonly used to quantify methane fluxes from landfill cover soil[9,10,11)]. Static flux chambers are relatively inexpensive, simple to set up and operate, and highly sensitive. The static flux accumulation chamber represents the most simple and coherent method to measure methane fluxes through the landfill surface and is one of the most frequently applied methods reported in technical literature[12)]. However, they can be deployed for only short periods without disturbing the measured surface, so no flux measurements are available between chamber deployments[11,13,14)]. Some disadvantages of static flux chamber method can affect the reliability of such methodology, including the high number of sample points required to obtain emissions from an entire landfill[12)] and possible interference with ordinary landfill actives[15)]. The high spatial variability of emissions necessitates a large number of chamber measurements to quantify whole-site emissions, making the chamber measurements approach time consuming and labour intensive. Further, specific geostatistical techniques must be applied to flux chamber results for accurate determination of whole-landfill emissions[4,14]. For these reasons, chamber measurements are not well suited to whole-site assessments, but certainly can be valuable for localized studies. Point measurement of subsurface gas concentrations and of pressure gradients with calculation of diffusive and pressure-driven flux face similar problems due to high spatial variability[4,10].

Other methods to measure emissions are mobile FID (Flame Ionization Detectors) and micrometeorological measurements, also known as Eddy Covariance method. Eddy Covariance method is micrometeorological technique of high-speed flux measurements of water, gas, heat, and momentum within the atmospheric boundary layer. An advantage of this method is easy automation, which enables measurements over longer periods and the possibility of simultaneous monitoring of methane and carbon dioxide emissions[16]. The method is able to run for weeks to several months, giving a good indication of both temporal variability and average emissions. Further advantages are the compact size of the required equipment its ease of operation[13]. A drawback of the method seems to be the limited footprint of the method, as a result of which it might not produce representative emissions from the entire landfill. Other disadvantages are the sensitivity of the method for the landfill topography, expensive, and require specialized equipment[10].

Portable gas detectors are hand-held or mounted devices that typically utilize one of the following methods of analysis: flame ionization, thermal conductivity, or photoionization. Flame ionization detectors (FID) are most commonly used for landfill applications. When held 5-10 cm above the surface, they can capture point source emissions. The success of these technologies in providing a representative analysis of the site’s emissions is largely dependent on the sampling methodology. A poor sampling scheme can potentially miss the hot spots. Portable FID is used for instantaneous landfill surface monitoring. The landfill is separated into a grid and samples are taking quarterly. The allowable limit for methane concentration is 500 ppmv (parts per million volume) above background concentrations. The advantages of this method are simple, fast, highly sensitive, multiple gases, and low cost. However this method has some disadvantages, these are may miss hot spots, high number of measurements required for large areas, uncertainty in extrapolation to whole area emissions using the area contributing to flux[17].

Instead, we propose a simple method for the quantification of whole-site methane emissions. The method is named Laser Method which is used the Laser Methane Detector as main equipment. This method is divided into three kinds of methods: hanged-LMD, held-LMD, and Laser Scanning (SS) Method. These methods involve scanning and pointing the ground surface or measured area with an LMD to measure ambient methane concentration.

We conducted two studies: lab scale and field study/measurements. The study sites were in EN30, Ito campus, Kyushu University lab and in Tamangapa landfill, Makassar city, South Sulawesi Province, Indonesia for lab scale and field study, respectively. This landfill type is open dump solid waste disposal site.

The objectives of these studies are to describe methane concentrations (underground and ambient) and flux profile from different flow rates, wind speed, and cover utilization; to perceive the influence of wind speed and cover utilization of LMD in ambient methane concentrations measurements; to cognize the relationship between ambient methane concentrations and methane flux; to estimate methane emissions from the relationships; and to describe spatial distribution from methane emission estimation.

In these studies, which are divided into two studies: lab scale and field study, we proposed a new method, named the Laser Method. Laser Methane Detector (LMD) was used as the main equipment in this method. This method is divided into three methods: hanged-LMD, held-LMD, and Laser Scanning (LS) method. Hanged-LMD and held-LMD method will produce point data while LS method will produce continuous data which is adjusted to point data. LS method is only special for field study, directly on landfill, because this method measuring the ambient methane concentration by its scanning.

2. Methodologies, Results, and Discussions on Lab Scale Study

The lab scale study was undertaken in EN30, lab of Kyushu University. We make a small scale or model of the landfill with the tub filled by gravel and soil as same as with the properties of the gravel and soil from landfill. Both have high permeability to allow methane flow through it. This small scale of landfill was built from box tub with square base size 75 x 55 cm^2 at height of 30 cm.

The methane source was derived from methane tank which is connected with flow meter by plastic tube. The flow meter is used to control methane flow rate from methane tank. Another flexible plastic tube (Ø 1cm) was placed on the base of tub with spiral shaped. This plastic tube was connected with plastic tube from methane tank. Previously, the tube which is placed in tub base was perforated by using auger. Holes are made along the tube which allows methane to flow through it. Moreover, in this study, 1, 2, 3, 4, 5, and 6 L min^{-1} are used as the methane flow rates because these flow rates could generate methane concentrations as same as with concentrations from landfill.

To avoid wind influence and any other interference from outside of the tub, two side of wall was placed in left and right side of the tub and cover utilization (without and with using the cover). In this study, we conducted four kinds of measurements of methane concentrations: vertical ambient methane concentrations with hanging-LMD, horizontal ambient methane concentrations with held-LMD method, methane flux with chamber method, and underground methane concentrations with gas monitor. All of these measurements were conducted in six of methane flow rates.

2.1 Measurements of methane concentrations and flux in a lab scale study

2.1.1 Measurement of underground methane concentrations by gas monitor

Prior to measure underground methane concentrations, we make four holes every 5 cm from the tub surface along the tub depth. These holes were named hole #1, #2, #3 and #4, with depth -5, -10, -15, and -20 cm from tub surface, respectively. Diameter of the hole was 0.5 cm and sealed. We opened the seal at one hole and connect that hole with gas monitor tube, as seen in **Fig. 1**. We waited for 2-3 minutes until the monitor stop measuring the gas concentration. Then, the underground gas concentration can be read from the display of gas monitor. We used GA 2000 as a gas monitor in this study, which can show the underground methane concentrations in % of unit.

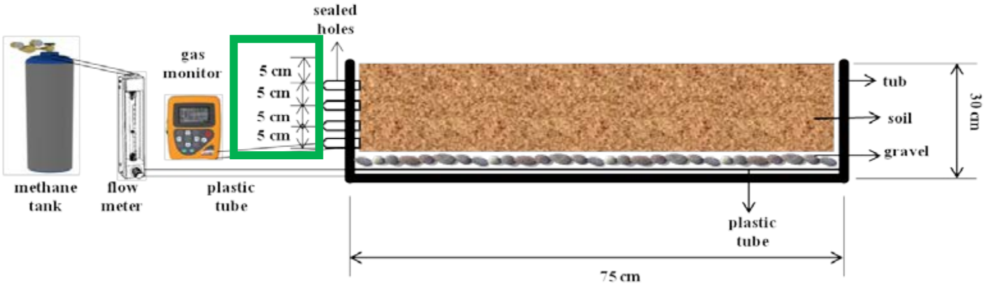


Fig. 1 Measurement of underground methane concentrations by gas monitor.

2.1.2 Measurement of methane flux by chamber method

Methane flux was measured by chamber method using the LMD mounted on a small chamber, with height of 55 cm, as shown in **Fig. 2**. We make four grids on the surface, named position #1, #2, #3, and #4 and then measured the flux on each grid. Methane flux in each grid was measured once for 1 min. We converted methane concentrations (ppm-m) as measured by LMD to methane flux (g m^{-2} h^{-1}) according to the following equation[18]:

$$F = \rho \times \frac{V}{A} \times \frac{\Delta C}{\Delta t} \times \frac{273}{(273+T)} \times 10^{-6} \times 3600 \qquad (1)$$

with F is methane flux [g m^{-2} h^{-1}]; ρ is gas density [g m^{-3}], for methane = 714 g m^{-3}, V is volume of chamber [m^3]; A is area of chamber base [m^2]; $\Delta C/\Delta t$ is slope of change in methane concentrations [ppm] over time [h]; T is average of temperature in chamber [°C].

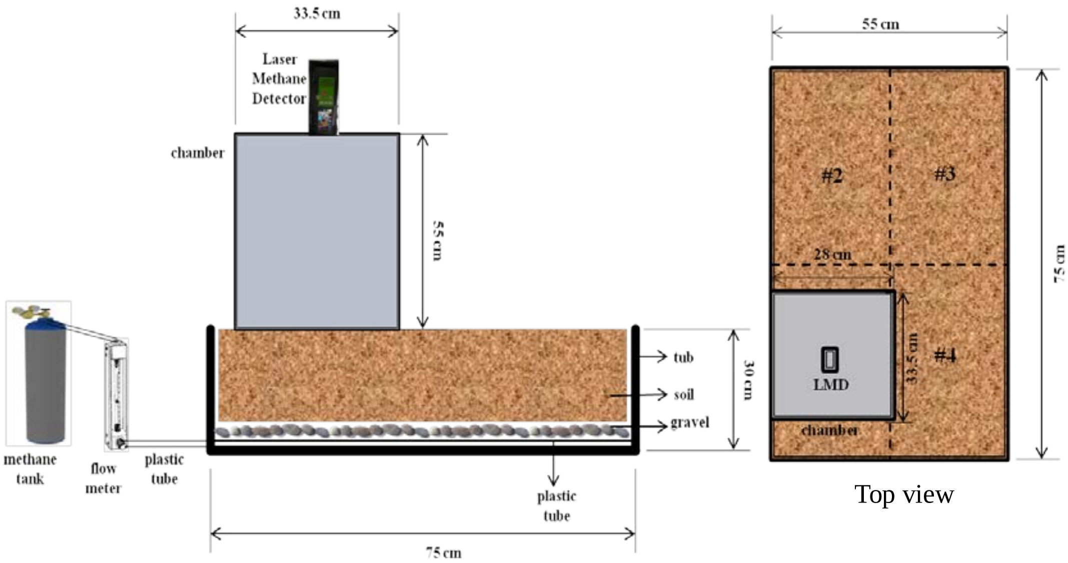


Fig. 2 Methane flux measurement by chamber method.

2.1.3 Measurements of ambient methane concentrations

Vertical and horizontal ambient methane concentrations were measured by Laser Method with an LMD and tablet PC as a data logger. In lab scale study, Laser Method is divided into two ways of measurements: hanged-LMD and held-LMD method. The data logger will record data of ambient methane concentrations every 1 s. Both of these measurements were conducted in four conditions of wind speed: normal condition (0 m s^{-1}, no wind from fan), low speed (with average 2 m s^{-1}), middle speed (with average 4 m s^{-1}) and high speed (with average 6 m s^{-1}). These wind speed conditions are set by fan with three wind speed button: low, middle, and high.

2.1.3.1 Vertical measurement of ambient methane concentrations by hanged-LMD

This measurement used an LMD with data logger mounted on a rod between two poles shown in **Fig. 3**. In field study, this method recorded the data by scanning the surface, and then we adjusted the data to be a point data. In this lab scale study, the LMD was hanged at about 50 cm from surface. We divided the surface into four grids, and measured methane concentrations on the center of each grid. Ambient methane concentration in each grid was measured once for 1 minute. These four grids were named position #1, #2, #3, and #4. This measurement was undertaken in four main conditions: variations of methane flow rates (1, 2, 3, 4, 5, and 6 L min^{-1}), wind speed variation (0, 2, 4, and 6 m s^{-1}), position of LMD (#1, #2, #3, and #4), and cover utilization (without and with cover) measurement. In the bottom of cover, we used a transparent sheet to allow the laser from LMD through it. We used a cover in measuring ambient methane concentrations to avoid outside circumstances.

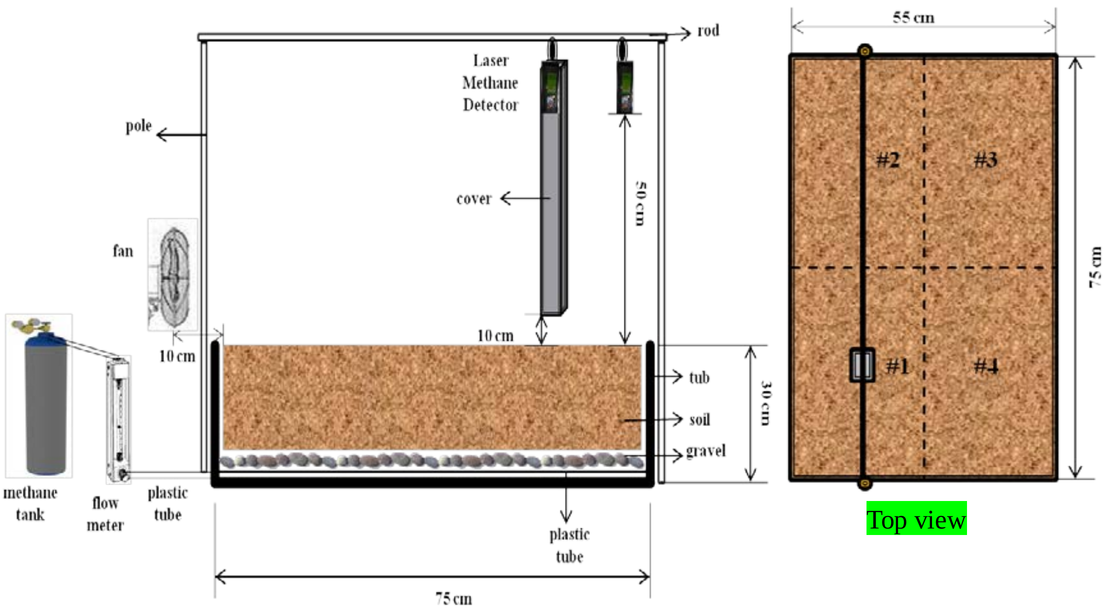


Fig. 3 Vertical measurement of ambient methane concentrations.

2.1.3.2 Horizontal measurement of ambient methane concentrations by held-LMD method

In this method, we measured ambient methane concentrations in horizontal way as shown in **Fig. 4**, with four main conditions: variations of methane flow rates (1, 2, 3, 4, 5, and 6 L min^{-1}), wind speed variation (0, 2, 4, and 6 m s^{-1}), and vertical position/height of LMD from the surface (0, 10, 20, 30, 40, and 50 cm). Ambient methane concentration in each height was measured once for 1 minute.

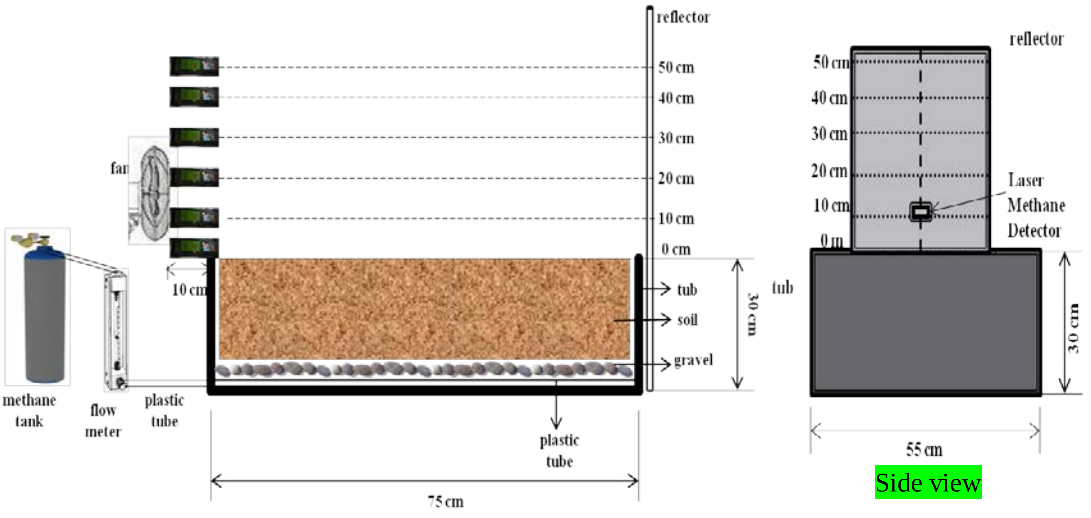


Fig. 4 Horizontal measurement of ambient methane concentrations.

2.2 Measurements results of methane concentrations and flux from lab scale study

2.2.1 Measurement of underground methane concentrations

Figure 5 below shows the result of underground concentrations measurement by gas monitor. This figure indicates that the increasing of flow rates and depths is followed by the increasing of underground methane concentration. Underground concentrations in 1 L min^{-1} (lowest flow rate) and 6 L min^{-1} (highest flow rate) are 6,600 – 8,100 ppm and 29,200 – 59,600 ppm, respectively. Moreover, underground concentrations in -5 cm depth (shallowest depth) and -20 cm (deepest depth) are 6,600 – 29,200 ppm and 8,100 – 59,600 ppm, respectively.

Pressure is directly proportional with the depth, therefore the highest pressure was occurred in the bottom area of the tub. Methane accumulates in a tub creates areas of high pressure. Gas movement is restricted by compacted gravel, soil, and areas of low pressure in which gas movement is restricted. The variation in pressure throughout the tub results in gas moving from high pressure to low pressure areas[5].

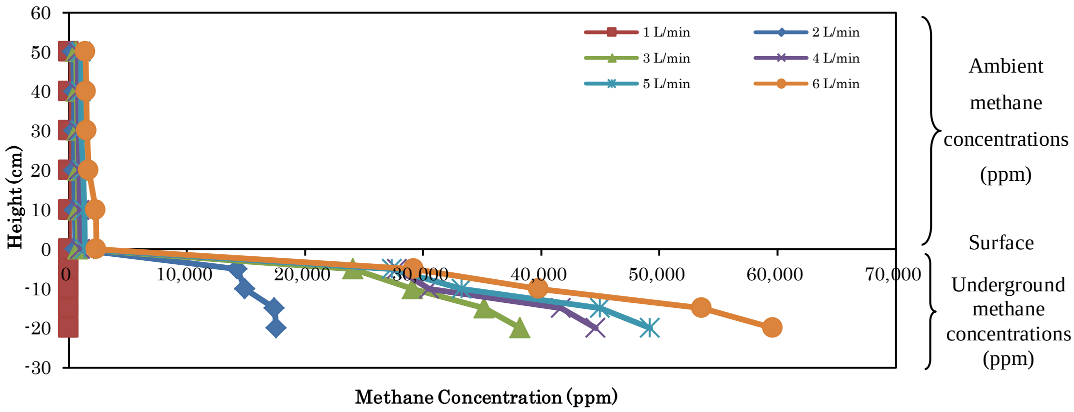


Fig. 5 Profile of methane concentrations from underground and ambient methane concentrations in different flow rates and height.

2.2.2 Measurement of methane flux by chamber method

Figure 6 show the results of methane flux measurement by chamber method. **Figure 6(a)** shows ambient methane concentrations in different sighting position of LMD (#1, #2, #3, and #4), which showed the small variability of concentration because this was conducted in same condition. This is in accordance with the previous study from Rachor and Gebert (2009)[19], which studied variation in emissions within the square meter and even at these small scale emissions proved to be highly heterogeneous.

Figures 6(a) and **6(b)** indicates that methane flux is directly proportional with the flow rates. The range of lowest and highest flux, in each flow rate are 20.08 – 23.97, 25.45 – 40.71, 44.40 – 68.10, 78.38 – 90.17, 97.58 – 108.71, and 115.01 – 137.26 g m^{-1} hr^{-1} for flow rate 1, 2, 3, 4, 5, and 6 L min^{-1}, respectively, as shown in **Fig. 6 (a)**. The average of those measurements are 21.23, 34.79, 56.98, 81.97, 101.87, and 123.87 g m^{-1} hr^{-1} for flow rate 1, 2, 3, 4, 5, and 6 L min^{-1}, respectively, as shown in **Fig. 6 (b)**, with its standard deviation.

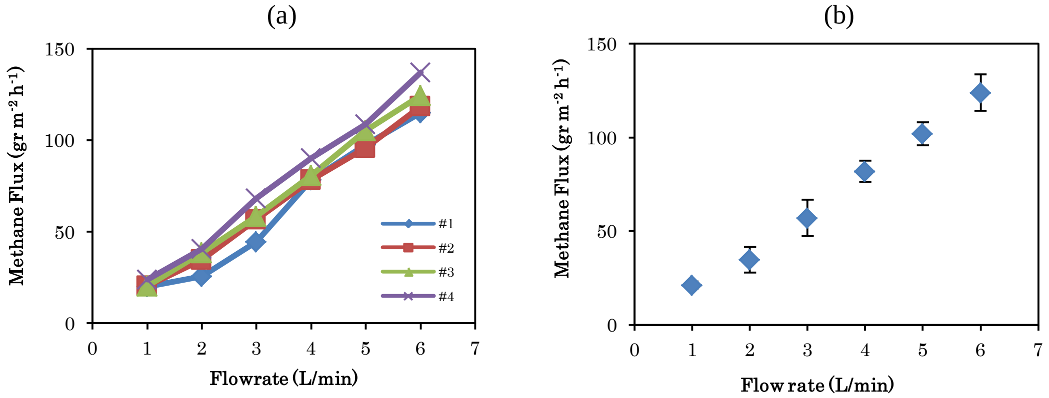


Fig. 6 Methane flux in different flow rates and chamber positions (a) and its average and standard deviations (b).

In fluid dynamics, flux is as defined as the rate of flow of a property per unit area and this is related to density of methane, soil, and air where methane is lighter than soil and air. Gravel and soil is a porous medium that the fluids follow through it. Methane from the tank will be measured by LMD as methane concentration inside the camber which is diffused from tub. Then the concentrations will be converted to flux by using Equation (1)[18].

2.2.3 Vertical measurement of ambient methane concentrations by hanged-LMD method

The results of vertical measurement of ambient methane concentrations are shown in **Fig. 7** and **Fig. 8**. These figures show ambient methane concentrations in different flow rates (**Fig. 7**) and wind speed (**Fig. 8**), without (a) and with (b) using a cover. These concentrations are the average from four positions (#1, #2, #3, and #4) of hanged-LMD. The average was used in the graphs as a representative from almost similar value from these four positions.

Figures 7(a) and **7(b)** below show that ambient methane concentrations are directly proportional with the flow rates. Highest flow rate generate highest concentrations. The average of ambient methane concentration in 0, 2, 4, 6 m s^{-1} of wind speed for without cover measurements are 368.62, 270.26, 128.63, 56,20 ppm for flow rate 1 L min^{-1}; 878.76, 360.92, 211.71, 107.80 ppm for flow rate 2 L min^{-1}; 1263.12, 668.58, 272.05, 193.90 ppm for flow rate 3 L min^{-1}; 1696.20, 888.35, 531.81, 262.42 ppm for flow rate 4 L min^{-1}; 2150.88, 1171.69, 732.53, 491.58 ppm for flow rate 5 L min^{-1}; and 2569.39, 1488.56, 999.25, 684.47 ppm for flow rate 6 L min^{-1}; respectively, as shown in **Fig. 7 (a)**.

Moreover, the average of ambient methane concentration in 0, 2, 4, 6 m s^{-1} of wind speed for with cover measurements are 266.01, 177.76, 138.49, 97.13 ppm for flow rate 1 L min^{-1}; 686.30, 382.54, 201.27, 137.80 ppm for flow rate 2 L min^{-1}; 1145.28, 821.80, 516.33, 389.32 ppm for flow rate 3 L min^{-1}; 1493.21, 1165.69, 874.34, 649.46 ppm for flow rate 4 L min^{-1}; 2039.48, 1560.77, 1120.46, 904.98 ppm for flow rate 5 L min^{-1}; and 2562.31, 1884.24, 1670.78, 1225.85 ppm for flow rate 6 L min^{-1}; respectively, as shown in **Fig. 7 (b)**.

Standard deviations from measurement with cover are lower than without cover measurement. These adduce that the data points from with a cover measurement tend to be closer to the mean as an expected value, whereas high standard deviation directs that the data is spread out over a large range of values.

(a) (b)

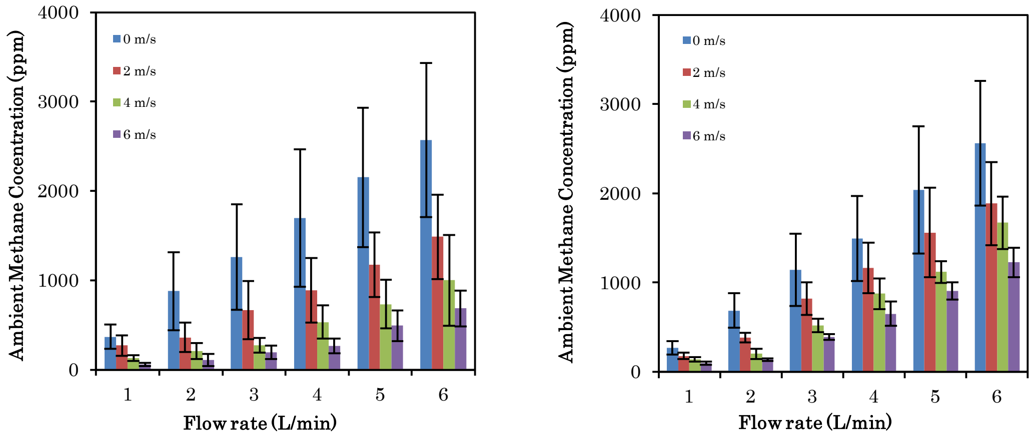


Fig. 7 Ambient methane concentrations in different flow rates, without (a) and with (b) cover.

(a) (b)

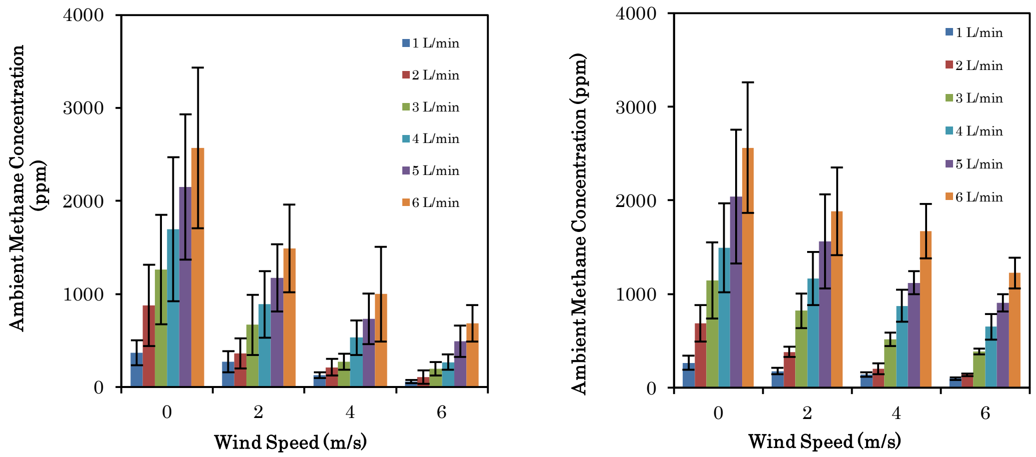


Fig. 8 Ambient methane concentrations in different wind speed, without (a) and with (b) cover.

Figures 8(a) and **8(b)** above direct that highest concentrations in each flow rate occurred in normal (no wind from fan, 0 m s^{-1}) condition. The average of ambient methane concentration in 1, 2, 3, 4, 5, and 6 L min^{-1} of flow rates for without cover measurements are 368.62, 878.76, 1263.12, 1696.20, 2150.88, 2569.39 ppm for wind speed 0 m s^{-1}; 270.26, 360.92, 668.58, 888.35, 1171.69, 1488.56 ppm for wind speed 2 m s^{-1}; 128.63, 211.71, 272.05, 531.81, 732.53, 999.25

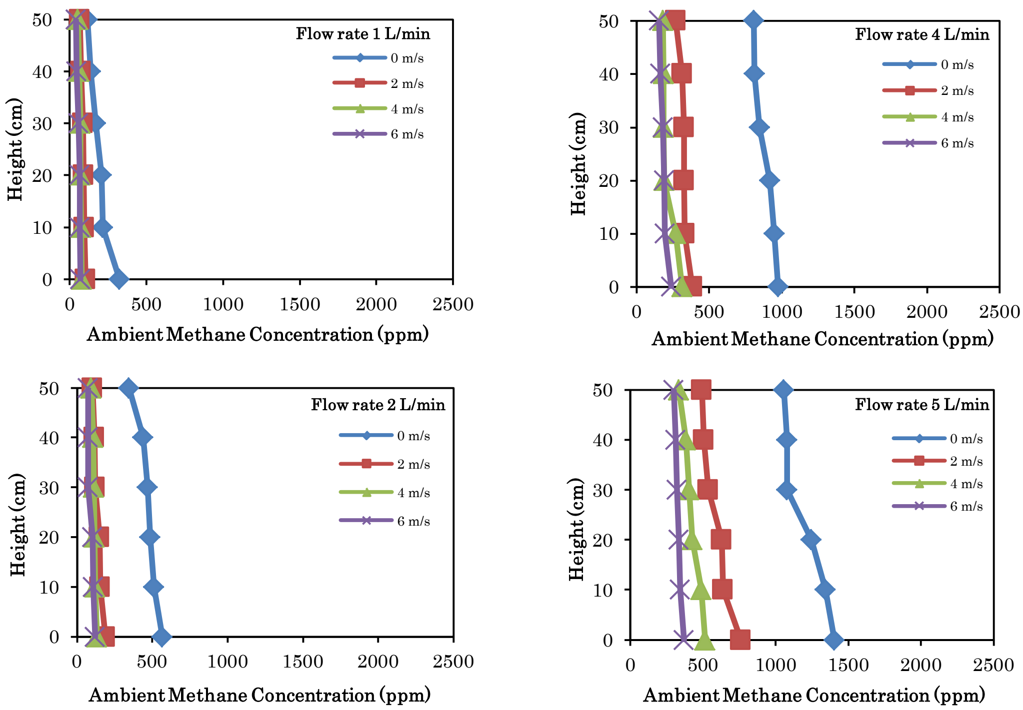
ppm for wind speed 4 m s^{-1}; and 56.20, 107.80, 193.90, 265.42, 491.58, 684.47 ppm for wind speed 6 m s^{-1}; respectively, as shown in **Fig. 8 (a)**.

Furthermore, **Fig. 8 (b)** is shown the average of ambient methane concentration in 1, 2, 3, 4, 5, and 6 L min^{-1} of flow rates, respectively, for with cover measurements are 266.01, 686.30, 1145.28, 1493.21, 2039.48, 2562.31 ppm for wind speed 0 m s^{-1}; 177.76, 382.54, 821.80, 1165.69, 1560.77, 1884.24 ppm for wind speed 2 m s^{-1}; 138.49, 201.27, 516.33, 874.34, 1120.46, 1670.78 ppm for wind speed 4 m s^{-1}; and 97.13, 137.80, 389.32, 649.46, 904.99, 1225.85 ppm for wind speed 6 m s^{-1}.

As same as with **Figs. 7 (a)** and **7 (b)**, standard deviations from with cover measurement are lower than without cover measurement. These indicate that with cover measurement more precise than without cover measurement. These results indicate that wind speed has an influence in ambient methane concentrations. This is in accordance with the one of methane properties, lighter than air in ambient temperature. Methane naturally released into the air at the tub or landfill surface which is carried by wind. The wind dilutes the methane with fresh air as it moves it to areas beyond the landfill. Wind speed and direction determine methane concentrations in the air, which can vary greatly from day to day, even hour by hour[5)].

2.2.4 Horizontal measurement of ambient methane concentrations by held-LMD method

Figure 9 below shows the results of horizontal measurement of ambient methane concentrations by held-LMD method. Ambient methane concentrations in the lowest flow rate (1 L min^{-1}) at 0 cm and 50 cm of height, respectively, are: 325.02, 114.21 ppm for wind speed 0 m s^{-1}; 100.98, 63.97 ppm for wind speed 2 m s^{-1}; 76.02, 53.62 ppm for wind speed 4 m s^{-1}; and 68.14, 41.82 ppm for wind speed 6 m s^{-1}, as shown in **Fig. 9**. Whereas, ambient methane concentrations in the highest flow rate (6 L min^{-1}) at 0 cm and 50 cm of height, respectively, are: 2376.38, 1420.235 ppm for wind speed 0 m s^{-1}; 2308.70, 793.28 ppm for wind speed 2 m s^{-1}; 2264.58, 634.6 ppm for wind speed 4 m s^{-1}; and 1564.44, 395.00 ppm for wind speed 6 m s^{-1}.



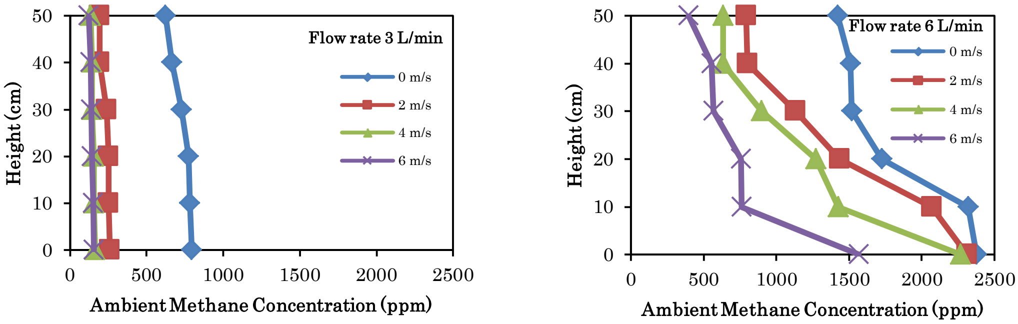


Fig. 9 Ambient methane concentrations in different flow rates, wind speed, and height.

This figure indicates that ambient methane concentrations are directly proportional with the flow rates and inversely proportional with the height and wind speed. Lowest flow rate (1 L min^{-1}) generates lowest ambient concentrations, as well as with the highest (6 L min^{-1}) flow rate produce highest concentration. Furthermore, increasing of height and wind speed is followed by decreasing of concentrations. These are due to one of the methane properties: lighter than air. 50 cm is the farthest height from tub surface which allows methane dispersed by air (wind) and any other outside interference. The lowest wind speed (0 m s^{-1}) yielded highest concentrations than others and the highest wind speed (6 m s^{-1}) produce the lowest concentration. These results indicate that wind speed have much influences in ambient methane concentrations. The wind dilutes the methane with fresh air as it moves it to other areas.

2.2.5 Relationship (correlation) between ambient methane concentrations and methane flux

Figure 10 indicates the relationship or correlation between ambient methane concentration and methane flux, without (**Fig. 10(a)**) and with (**Fig. 10(b)**) cover. Theses figure show that ambient methane concentrations, from both measurements, are positively correlated with the methane flux and inversely proportional with the wind speed. The correlations are moderate and strong correlation with the R^2 within 0.7988 – 0.9903 and 0.8820 – 0.9829 for without and with cover measurement, respectively. For both measurements, highest concentrations were occurred in 0 m/s of wind speed with 2569.39 ppm and 2562.31 ppm for without and with cover measurement, respectively. Whereas the lowest concentrations were happened in 6 m/s of wind speed with 56.20 ppm and 97.13 ppm for for without and with cover measurement, respectively.

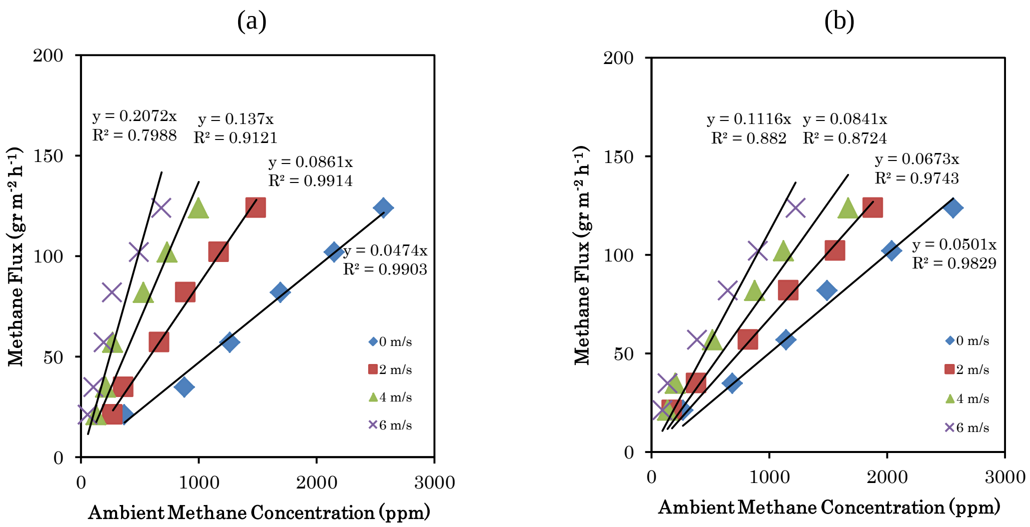


Fig. 10 Relationship (correlation) between methane flux and ambient methane concentrations without (a) and with (b) cover.

From these figures, range data between different conditions of wind speed in without cover measurement is further than with cover measurement. It could be indicated that wind speed give influence into measurement, than the cover one. Measurement with using a cover could prevent interference from outside and become more precise.

This relationship (correlation) equation could be used to predict methane emissions. Ambient methane concentration which is derived from measurement is place as X variable and the result is Y as the methane flux estimation. Then, we multiplied it with measured areas will yield a value of methane emissions (gr/hr).

3. Methodologies, Results, and Discussions on Field Study

3.1 Measurement of ambient methane concentrations and methane flux in a field study (direct measurements)

The field study was carried out in Tamangapa landfill which is lies on Makassar city, Indonesia. In this study, we conducted three kinds of measurements of methane concentrations: ambient methane concentrations with LS and held-LMD method; and methane flux with chamber method. Measurements in field study have same procedure with the lab scale measurements. The difference lies in measured area and dimensions of equipments. All of ambient measurements were carried out without cover utilization because when we held the field study, the wind speed on those days within range 0 – 1 m s^{-1}. The methodologies of these measurements will be described in the following sections.

3.1.1 Study site

Tamangapa landfill lies 15 km from Makassar City, South Sulawesi Province, Indonesia (**Fig. 11**), which is owned and operated by Parks and Sanitation Agency, Municipal Government of Makassar City. It covers 14.3 ha and is divided into nine zones, identified as A, B, C_1, C_2, C_3, D, E_1, E_2, and F. B, C_1, C_2, E_2, and F are active zones while other zones are closed. We conducted the field study in one active zone: zone E_2. This zone is undisturbed zone from scavenger and vehicle. Moreover, this zone has highest concentration than other active zones, which is shown by many hot spots area.

This landfill was opened in 1993 and will close in 2016. The main deposits are municipal solid wastes from Makassar city, which average 500 ton per day. The site is open dumps, no daily cover soil, no vegetation, and now the waste having reached a depth of 20 m. When the study was conducted, wind velocity has a low speed, within range 0 – 1 m s^{-1}.

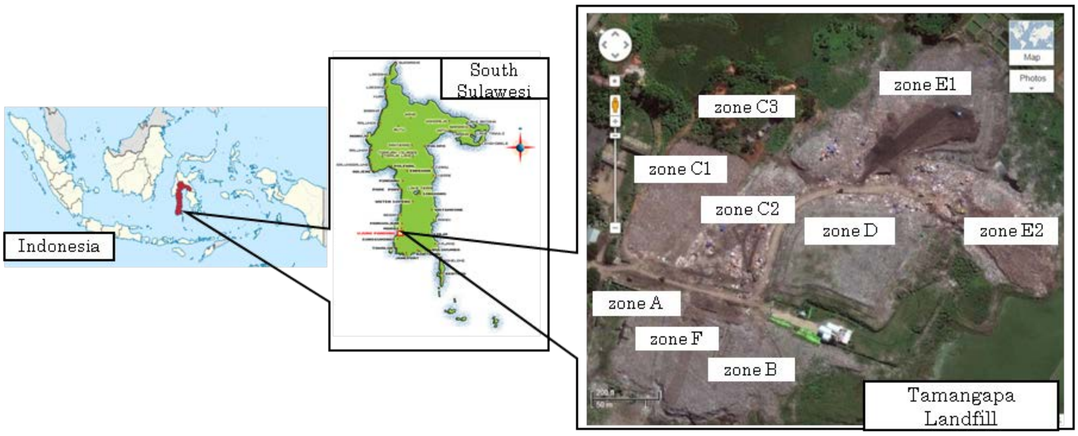


Fig. 11 Tamangapa landfill in Makassar city, Indonesia.

3.1.2 Measurement of methane flux by chamber method

In field study, methane flux was measured by chamber method, same method with the lab scale study. We measured the flux in 20-m × 20-m grid, which is divided into 16 small grids, where each small cell was measured once for 5 min. The data from this method is a point data.

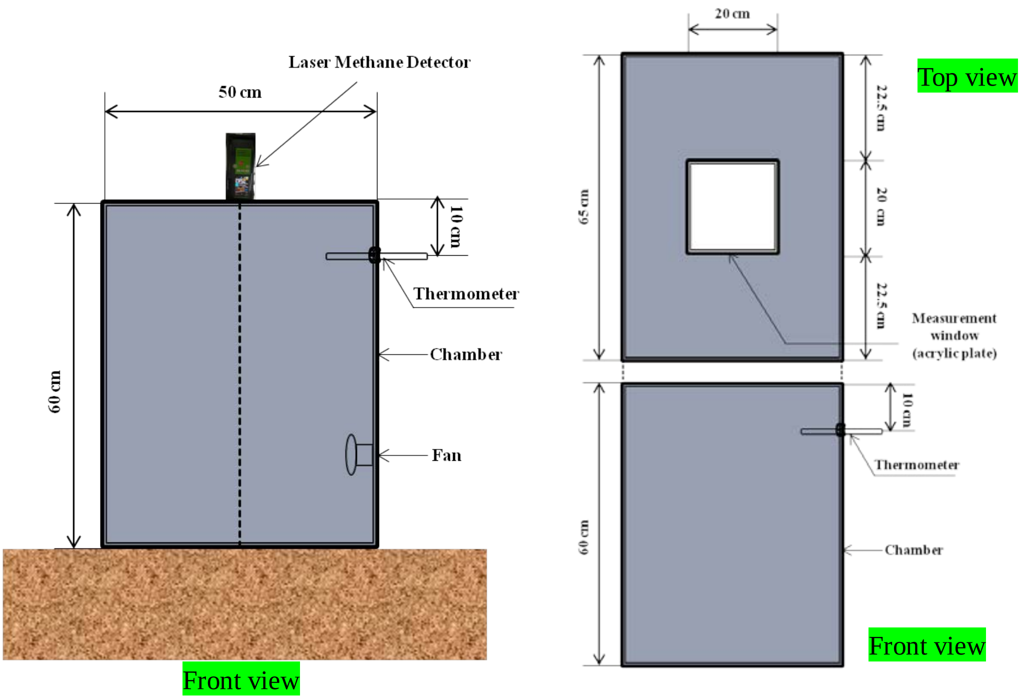


Fig. 12 Chamber dimensions and methane flux measurement in field study.

3.1.3 Measurement of ambient methane concentrations by held-LMD method

We also measured ambient methane concentration by held-LMD method in 2.5-m × 2.4-m grid (@ 0.5-m x 0.6-m grid) inside zone E_2, as shown in **Fig. 13**. The LMD was held at about 1.5 m above the surface and produced point data. This measurement was measured once for 30 s and to perceive the ambient methane concentration in small scale area. This measurement was carried out without cover because of the very low wind speed on that time.

Fig. 13 Measurement of ambient methane concentration with held-LMD method.

3.1.4 Measurement of ambient methane concentrations by Laser Scanning (LS) Method

The scanning method, named Laser Scanning (LS) Method, uses an LMD mounted on a wire strung between two poles (**Fig. 14**). The poles were placed initially at two corners of the cell in a north–south orientation. The wire between the poles was held taut by two people, who drew the LMD alternately towards themselves with a reel, that each held, as seen in **Fig. 15**. The LMD was held at about 1.5 m above the surface. The data logger recorded the ambient methane concentration every 1 s and produced continuous data. The poles were then moved 1 m across and the measurement was repeated. It took about 20 min to cover the lines entire measured area 20-m × 20-m. This measurement was conducted in one active zone of the landfill with the highest hot spot area inside the zone. As well as with the held-method, this method is not using a cover in measurement due to the low of wind speed.

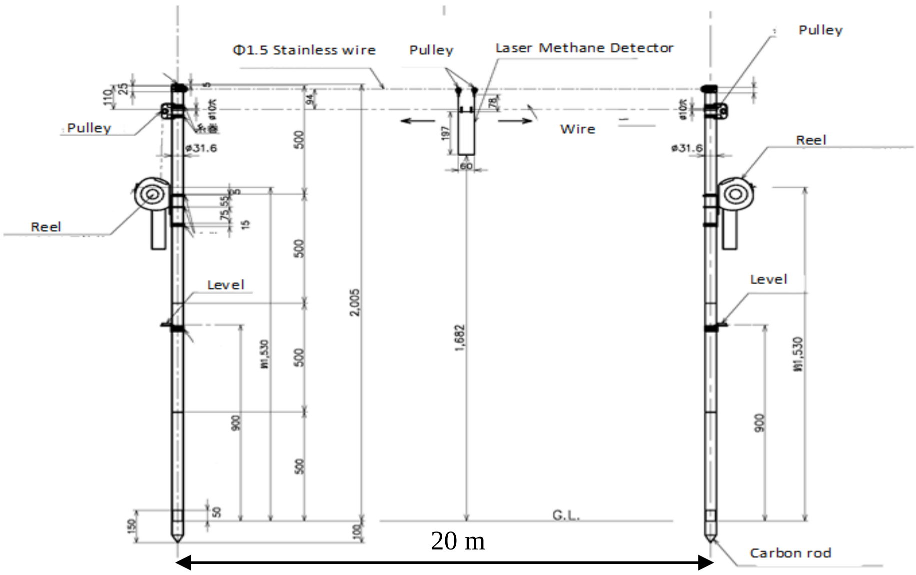


Fig. 14 Scheme of Laser Scanning (LS) Method.

Fig. 15 Measurement of ambient methane concentration by LS method.

3.2 Relationship (correlation) between ambient methane concentrations and methane flux from field study

The field study was conducted to estimate methane emissions from real landfill with Laser Method which is divided into held-LMD and LS method. This study was only undertaken in ambient measurement without a cover. **Figure 16** below shows the relationship (correlation) between methane flux and ambient concentrations from field study by held-LMD (**Fig. 16(a)**) nd LS method (**Fig.16(b)**).

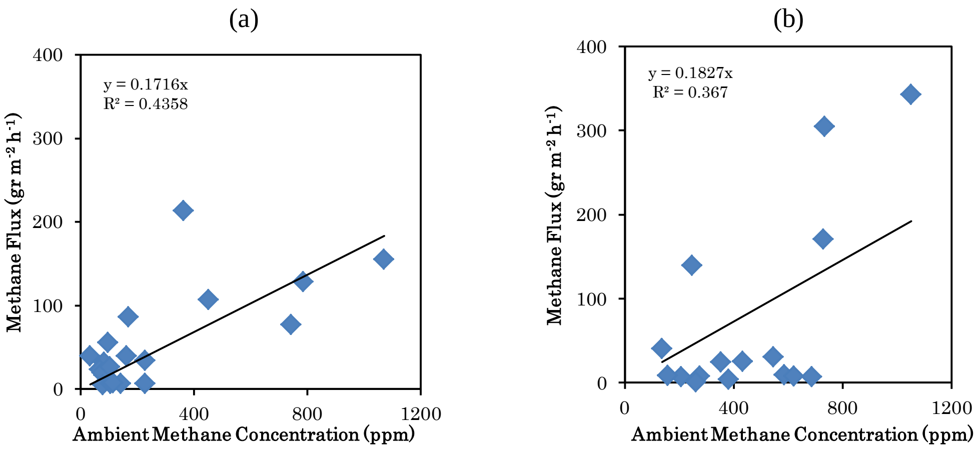


Fig. 16 Correlation between methane flux and ambient methane concentrations from field study by held-LMD (a) and LS method (b).

Methane flux was positively correlated with ambient methane concentrations, as shown in **Fig. 16**, which R^2 = 0.4358 for held-LMD method and R^2 = 0.367 for LS method. This correlation yielded a weak correlation which the equation can be seen in **Fig. 16**. The weak correlation probably due to outside interference come into measurement because no cover utilization. Correlation between methane flux and ambient methane concentration from LS method was lower than held-LMD method. Correlation in **Fig. 16 (a)** is a correlation between point data from chamber method and held-LMD method. Meanwhile, correlation in **Fig. 16 (b)** is correlation between point data from chamber method and continuous data from LS method, which is adjusted to point data. The scanning process of the LS method has the limitation to cover all area inside the grid, its cover line by line within 1-meter distance in 20 m × 20 m grid; it has possibility to miss the hotspots between the lines.

This correlation equation could be used to estimate methane flux in a landfill because it was conducted in the highest concentration of the zone. Then, the results will be multiplied with the zone area and yielded the estimation of methane emissions. Methane emissions estimation from held-LMD and LS method, derived from equation above, are 213.54 Gg/yr and 164.69 Gg/yr. Methane emissions estimation, which is obtained from the LS method, could be described in a contour graph, as seen in **Fig. 17**.

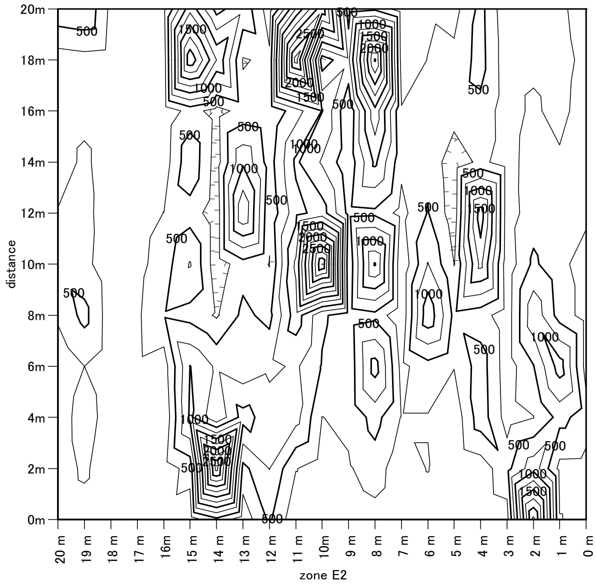


Fig. 17 The spatial distribution of methane emissions estimation by LS method.

Figure 17 above shows the spatial distribution of methane emissions in a contour graph which is derived from correlation equation between methane flux and ambient methane concentration by LS method. This figure indicates the high spatial variation and distribution in 400 m^2 of methane emissions which is measured by LS method. The hot spots area inside the measured grid could be captured by this method.

In further study, we will use a cover to avoid any other interference come into measurement. According to the lab scale study, measurements with using a cover become more precise in any other wind speed condition. Furthermore, these results show that our method may be used to estimate methane emissions in a landfill in combination with methane flux.

4. Conclusions

The following conclusions can be drawn.

(1) A new method is proposed, named Laser Method. This method uses the Laser Methane Detector as main equipment. This method was divided into three methods: hanged-LMD, held-LMD, and Laser Scanning method (LS) method. The LS method could only be implemented in field study (landfill).

From lab scale study;

(2) Methane flux was positively correlated with ambient methane concentrations. The correlations are moderate and strong correlation. These are probably due to wall and cover utilization. Moreover, the linear regression line from measurement with using a cover tends to be adjacent each other than measurement without using a cover. It means cover has an advantage to

prevent wind influence and outside interference.

(3) The correlation equation, linear regression equation, could be used to predict methane emission in other area. X variable is the measured concentration of ambient methane and Y is the estimation of methane flux. Then, this Y will be multiplied by measured area and yield methane emission value (gr/hr).

(4) Ambient methane concentration, which is measured by hanged-LMD and held-LMD method, is inversely proportional with the wind speed and height. Variations of wind speed provide much influence to measurements. The highest speed of wind produces the lowest of ambient methane concentrations. This is in accordance with the one of methane properties, lighter than air in ambient temperature.

(5) Cover utilization in ambient measurements indicate wind has an influence that could affect the measurements. Measurements with using a cover tend to be a more precise than without cover measurements. A cover could avoid the wind influence and outside interference come to measurements.

From field study;

(6) Laser Scanning (LS) method is a scanning method of Laser Method, which produced continuous data. This method is effective, efficient, and may detect the hot spots even in a small scale area. It needed only 20 min to measure ambient methane concentrations across 400 m^2.

(7) Ambient methane concentration, which is measured by held-LMD and LS method, has a positive and weak correlation with methane flux. This weak correlation is probably due to no cover utilization in measurement. Therefore, outside interference could come into measurements.

(8) Held-LMD method is more accurate than LS method, however this method is time consuming and only could cover small area in one set measurement. Meanwhile, the LS method is less accurate than held-LMD method, nevertheless it could save much time and could be conducted in large area in one set measurement.

(9) As well as with the lab scale study, the correlation equation from field survey could be used to estimate methane emissions and describe the spatial distribution of the emissions in a landfill.

(10) The LS method has some drawbacks, this method could not cover all area in a one cell, only the measured lines, with 1-m distance between the lines. It has high possibility to miss the hotspot between the measured lines and resulting uncertainty in extrapolation to estimate methane emissions in the entire landfill.

(11) In future work, cover measurement will be used and wind speed and wind direction will be measured precisely. Furthermore, we will use numerical analysis with COMSOL 4.2 as software to estimate methane emission in the entire landfill based on Laser Method data.

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