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METHANE EMISSION REDUCTION IN PALM OIL MILL THROUGH CO-COMPOSTING EMPTY FRUIT BUNCH AND PALM OIL MILL EFFLUENT*

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Abstract

The objective of this research is to evaluate methane emission reduction in palm oil mill through composting of empty fruit bunch. Experiment was conducted at a palm oil mill in Pangkalan Bun, Central Kalimantan, Indonesia. The composting period for the existing process was 30 days. In this experiment we also arranged 92.975 ton empty fruit bunch in two piles for composting period of 80 days. Each pile was sprayed with palm oil mill effluent for about one hour every another day and was turned over mechanically in between to facilitate aeration. This spraying and turning was terminated a week and two weeks before harvesting, respectively for 30-day and 80-day composting periods. Compost quality, palm oil mill effluent consumption, and methane emission were compared for both composting periods. Result showed that compost yield of 74.4% was achieved from 30-day composting period with 2.38 m^3 of palm oil mill effluent consumption for every ton of empty fruit bunch. The numbers increased to 93.6% and 4.30 m^3 for 80-day composting period. Total methane emission reduction is 35.92% and 53.22% for 30-day and 80-day composting period, respectively, as compared to that of mill without co-composting process.

Keywords: windrow co-composting, empty fruit bunch, palm oil mill effluent, methane emission

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1. Introduction

Indonesia is now the leader in crude palm oil (CPO) producer contributing of about 46.6% of the world. By 2017 CPO production of Indonesia has reached 31.49 million ton from a total oil palm area of 11.20 million hectare (Statistics Indonesia, 2018). The process of CPO extraction also produce significant amount of wastes, namely empty fruit bunches (EFB), palm oil mill effluent (POME), mesocarp fiber, shell, and boiler ash (Hasanudin, 2007). Without proper management, all of these wastes may cause environmental problems.

The EFB is the largest solid waste generated from a palm oil mill (POM) during threshing process (accounted for 20.0–23.0%). EFB is high in moisture content and consists of main stalk (20–25%) and numerous spikelets (75–80%) with sharp tips (Lee and Ofori-Boateng, 2013). So far, EFB is returned to oil palm plantation as mulch or compost, which in the long term will be a source of organic material for the soil, thus saving the use of chemical fertilizers. Generally EFB is piled in between of oil palm three rows or at around oil palm threes. However, EFB piles often becomes a nest of pests such as beetles and mice that are harmful for the oil palm (Bessou et al., 2017). It is important, therefore, to develop other methods to treat EFB in a better way. One option that is interesting to consider is co-composting EFB and POME. Composting is a controlled biological process which converts solid organic matter into a stable humus-like substance which is suitable as a soil conditioner and has a certain nutrient value, too. In this way, EFB is piled to form long mound, whilst POME is sprayed over. The pile is turned over periodically to increase mixing between EFB and POME as well as to facilitate oxygen and temperature management. POME utilization for composting process significantly reduces the amount of POME treated in the wastewater treatment plant (WTP) which in turn decreases greenhouse gas emission.

During the composting process, the organic fraction is partially degraded by micro-organisms to carbon dioxide and water, whereas the other part undergoes a humification process which results in a stable compost having suitable characteristics to be used as bio-fertilizer (Baeta-Hall et al., 2005; Paredes et al., 2000; Tomati et al., 1996). To accelerate composting process the pile of composting materials are turned periodically. Co-composting of EFB and POME not only leads to considerable nutrient recovery, but also reduces global warming potential (Stichnothe and Schuchardt, 2010).

Machinery utilization during composting process, however, consumes fossil fuel that in turn emits methane gas into the atmosphere. In addition, electricity energy consumed to run a POME pump also emits methane gas. In between two consecutive turning periods, there is a chance of anaerobic condition in the piles that will also contribute to methane emission. As far as the authors are aware, the role of co-composting of EFB and POME on the methane emission reduction have not been studied in sufficient depth.

The main objective of this study is to evaluate the co-composting of EFB and POME using open windrow processing as an alternative method to effectively reduce methane emission from a POM. In this context, two different waste management scenarios were compared: common waste management (without composting) and improved management system (with co-composting EFB and POME).

This work is divided in two main parts:

- evaluating POM performance
- analysing composting performance and the related methane emission reduction.

2. Materials and methods

2.1. Location description

Research was conducted at a POM in Pangkalan Bun, Central Kalimantan, Indonesia. The POM was designed for an hourly capacity of 45 ton fresh fruit bunch (FFB). All of the EFB was delivered to the composting facility located around 500 m from the mill. At this area, EFB was composted with addition of POME pumped from a cooling pond of a nearby WTP. Composting facility has an overall area of 2 ha with 36 composting rows (Figure 1). Normally, each pile has a size of 100 m length resembles a long, small hill with 2 m width and 1.2 m height. The piles were separated by 0.3 m space for walking of spraying boys. Based on the composting area and mill capacity, composting process was designed to finish in 30 days. With this period the resulted compost was of medium mature. The company intentionally produces medium (half mature) compost because carbon in the compost will be slowly released during its application in the soil. The addition of POME into each composting pile was conducted every another day for about an hour. The piles were alternately turned over mechanically in between of spraying days to facilitate aeration. The pile spraying and turning was terminated a week before harvesting. The spraying termination was purposed for the pile to cure and to increase the maturity of the compost.

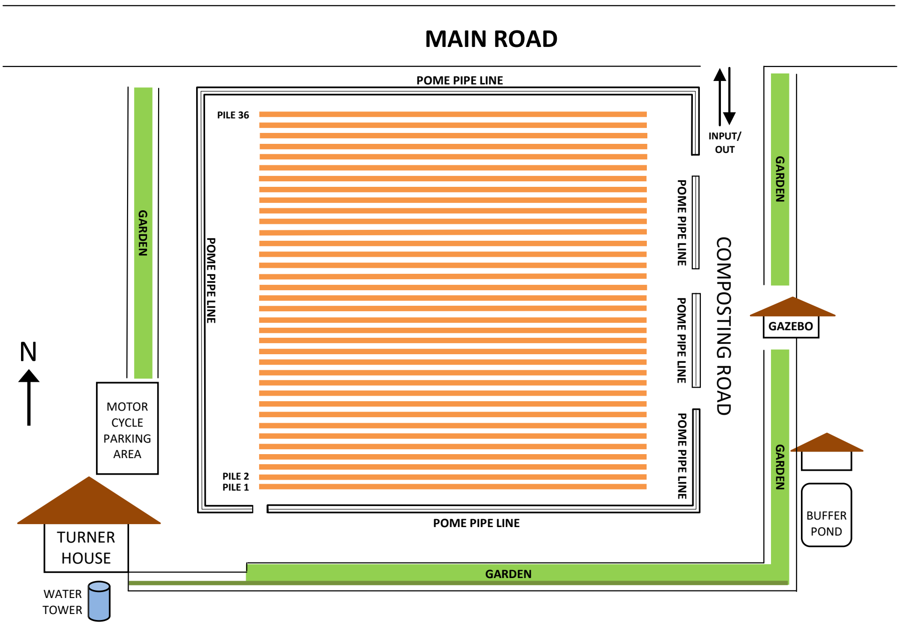

Fig. 1. Scheme of windrow co-composting EFB and POME investigated in this research

In this experiment we also extended composting period to 80 days. The prolonged period was purposed to get mature compost and to evaluate the effect of composting period on the methane emission reduction potential due to POME utilization. It was expected that the longer the period, the lower methane was emitted from POME anaerobic ponds due to more POME was co-composted. For this purpose, we used 92.975 ton EFB arranged in two piles with length of 45 m each. POME spraying and pile turning were conducted in the same way as for composting period of 30 days. For composting period of 80 days, POME spraying was conducted till the day of 66 (terminated two weeks before compost harvesting).

Changes of EFB characteristic (from fresh to compost) was observed from its carbon and nitrogen content which was analyzed using elemental analyzer (Elementar Vario EL Cube, Germany). Chemical oxygen demand (COD) of POME and leachate was analyzed using closed reflux method (Hach DRB 200) followed by spectrophotometry (Hach DR/4000 U). Emitted gas from the piles was also evaluated. Perforated polyvinylchloride tubes (2.5 inch diameter, 50 cm length) were planted in such arrangement representing bottom, middle, and top of the composting pile. The emitted gas from the pile was sampled in interval of 7 to 10 days by sucking it using a mini electric vacuum pump. Gas collection was conducted just before turning activity. The gas was collected in 1-L sampling bag prior to transferring it into vacuumed small glass tubes (10 mL). The gas composition was then analyzed in the lab using gas chromatography (Shimadzu GC 2014). The amount of methane gas released during composting process was calculated using carbon balance.

2.2. Calculation

Carbon balance was explored to calculate gas amount and methane emitted from the piles during composting process. Based on carbon balance (Figure 2), the amount of carbon gas (m_5C_5) released during composting process can be presented as:

$$(m_5)(C_5) = (m_1)(C_1) + (m_2)(C_2) - (m_3)(C_3) - (m_4)(C_4) \quad (1)$$

where m_1 through m_5 refers respectively to mass (expressed in ton) of EFB used for composting, POME sprayed over the compost pile, produced compost, leachate, and gases emitted from compost pile. Similarly, C_1 through C_5 refers respectively to carbon content of EFB, POME, compost, leachate, and emitted gases (all are expressed in % volume).

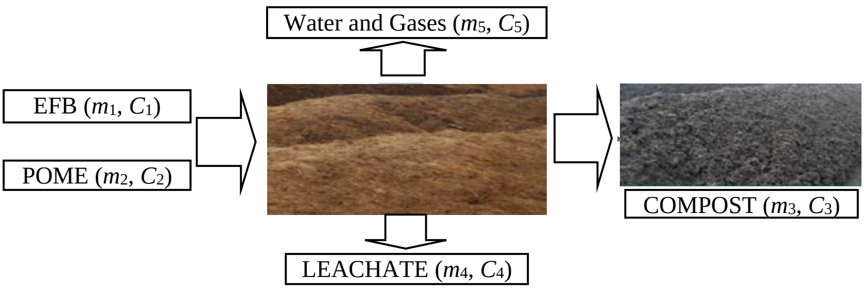

Fig. 2. Mass balance in composting process

Water balance was used to calculate water evaporation (W_5) during composting process according to the following relation:

$$(m_5)(W_5) = (m_1)(W_1) + (m_2)(W_2) - (m_3)(W_3) - (m_4)(W_4) \quad (2)$$

where W_1 through W_5 respectively is water content (% wb) of EFB used for composting, POME sprayed over, produced compost, leachate, and evaporation.

The equivalent methane emission resulted from compost pile ($CH_{4,P}$), presented in ton CH_4/ton FFB, is calculated as the following:

$$CH_{4,P} = [m_5C_5 \times [CH_4] \times (16/12)] / ((EFB_c)m_1) \quad (3)$$

where $[CH_4]$ is average of methane content in the gas (inert free) released from the composting pile, and EFB_c is EFB yield coefficient (per unit of processed FFB). Total methane emission reduction ($CH_{4,TOT}$) resulted during co-composting process of EFB and POME is calculated by:

$$CH_{4,TOT} = CH_{4,B}\,(X) - (CH_{4,P} + CH_{4,L} + CH_{4,F} + CH_{4,E}) \quad (4)$$

where $CH_{4,B}$ is baseline methane emission from POME treatment pond without methane capture, X is fraction of POME used for EFB composting (%), $CH_{4,P}$ is methane emission from composting piles, $CH_{4,L}$ is methane emission from leachate pond, $CH_{4,F}$ is methane emission from fossil fuel used to operate machinery, and $CH_{4,E}$ is methane emission due to electricity consumption to operate pump during the composting process. COD stabilization in anaerobic processes is directly related to methane evolution, so that baseline methane production from WTP can be calculated from the COD removal during POME treatment:

$$CH_{4,B} = \text{POME yield} \times [COD_{inlet} - COD_{outlet}] \times F_{CH4} \quad (5)$$

where POME yield is amount of POME released from CPO extraction process (m^3/ton FFB), COD_{inlet} and COD_{outlet} respectively is COD values of POME entering and leaving ponds of WTP (kg/m^3), and F_{CH4} is methane conversion factor. Theoretically, methane conversion factor is 0.35 Nm^3/kg COD removal (Grady et al., 1999), which is equivalent to 0.25 kg/kg. Treating POME in pond system has been reported to emit 237 g CH_4 per kilogram of COD removal (Yacob et al., 2006). We use this number as practical value (F_{CH4}) for anaerobic conversion of POME to CH_4 in wastewater treatment ponds.

3. Results and discussion

3.1. POM performance and composting yield

Data records for 17 months revealed that the POM was able to process a total of 330,834.60 ton FFB with a total POME of 265,614.50 m^3. This means that during oil extracting process in average 0.803 m^3 of waste water was released for every ton of FFB. This number is higher than the average value of 0.65 m^3/ton FFB (Schuchardt et al., 2008). Our measurement showed that fresh POME had a COD value of 80,250 mg/l and a density of 0.9917 kg/l or 0.9917 ton/m^3. After treatment in a series of ponds, the COD of the POME decreased to 8,725 mg/l where the treated POME was delivered to the oil palm plantation for irrigation. Our observation also revealed that for every ton of FFB being processed 147.5 kg (14.75% w/w) of EFB was produced with moisture content of 46.91% (wb). Here, EFB released from the mill has been pressed and shredded. Without pressing, the EFB is normally about 22% of the FFB (Hasanudin et al., 2015). Therefore, pressing was able to remove water from empty bunches by about 30 % of the EFB.

Important factors affecting the rate of decomposition of organic material, among others, include C/N ratio, moisture content, and aeration (Guo et al., 2012). The initial C/N ratio is one of the most important factors influencing compost quality (Michel et al., 1996). In general, the optimum initial C/N ratio for successful completion of compost is in between 25:1 and 30:1 (Kumar et al., 2010). Carbon, nitrogen, and hydrogen composition of fresh EFB and POME is presented in Table 1. From the table, EFB has a C/N ratio of 62.74 which is higher than the optimum values for composting process; while POME has a relatively low C/N ratio (20.27). Therefore, the addition of POME into EFB is important to lower the C/N ratio to the suitable values. During composting, moisture content is required for transporting the dissolved nutrients that is necessary for activities of microorganisms (Liang et al., 2003).

Total amount of POME consumption throughout composting process was 221.42 m^3 or 2.3815 m^3 per ton of EFB for composting period of 30 days. When composting period was extended to 80 days, POME consumption increased to 400.23 m^3 or 4.3047 m^3 per ton EFB, almost twice higher than that of 30-day composting period. Referring to EFB/FFB ratio of 14.56%, then the amount of POME sprayed during composting corresponded to 0.347 m^3/ton of FFB for composting period of 30-day, and 0.627 m^3/ton of FFB for composting period of 80-day. This implied that POME consumed for composting was 43.18% and 78.04% for period of 30 and 80 days, respectively. Compared to the reported work (Schuchardt et al., 2002), POME utilization in our work was higher than the optimum value. It was reported that within 9 weeks the optimum amount of POME addition is 3.2 m^3/t EFB for roofed windrow, and the maximum is up to 4.5 m^3/t EFB for open windrow (Schuchardt et al., 2002).

Table 1. Water content (MC) and composition of Carbon (C), nitrogen (N) and hydrogen (H) of POME, EFB and compost

Material	***MC (%, wb)***	***C (%, db)***	***N (%, db)***	***H (%, db)***	***C/N***
EFB	46.91	54.43	0.96	5.56	62.74
POME	93.47	44.45	2.91	6.82	20.27
Compost 30-day	68.81	50.71	2.25	7.40	22.56
Compost 80-day	75.76	50.71	3.36	7.29	15.11

Note: db = dry basis; wb = wet basis

Fig. 3. High evaporation from a composting pile during turning operation

Based on Eq. (2), we performed water balance calculation and found that during composting process, water was evaporated as much as 72.14 l/d per ton EFB or 37.26 mm/d for 30-day composting period, and 48.72 l/d per ton EFB or 25.17 mm/d for 80-day period. Other work reported evaporation rate of 51 l/d per ton of EFB at the same turning frequency, 3 times a week (Schuchardt et al., 2002). The high evaporation was clearly witnessed especially during operation of turner machine which generating smoke like water vapor as presented in Figure 3. This evaporation rate was much higher as compared to natural water evaporation. Therefore, the addition of POME is important in order to balance the high water evaporation during composting process. The high evaporation rate could be resulted from high composting temperature. Our observation monitored that temperature inside the pile reach in the range of 65.3 – 78.6 °C (thermophilic range) with average value of 71 °C.

Our observation for about three months noted 7348.01 ton EFB were delivered to the composting process. In the same period, it was harvested 5466.14 ton compost from 30-day period piles. This meant that compost yield is 74.39%. For 80-day composting period, 87 ton compost was produced out of 92.975 ton EFB. This number corresponds to a compost yield of 93.57%. Compost characteristic was presented in lower row of Table 1. It obvious that C/N ratio decreased from 62.75% (fresh EFB) to 22.30% for 30 days composting process, and to 15.11% for 80 days composting process. The decreasing value of C/N ratio implied that decomposition occurred during composting process.

It was also noted that during composting process, no leachate flowing to the leachate pond was observed. Very little leachate was just spread over the vicinity of the pile that can be ignored for calculation. Composting process also emitted gas with methane content as presented in Figure 4. Methane emission from composting pile is quite low, especially for composting period 30-day. The value increases with prolonged composting period, but still low (1.5% after 70-day composting period). Based on the graph we calculated average methane emission from 30-day and 80-day composting pile to be respectively 0.133% and 0.310% which is equivalent to 2.183 and 4.905% inert free.

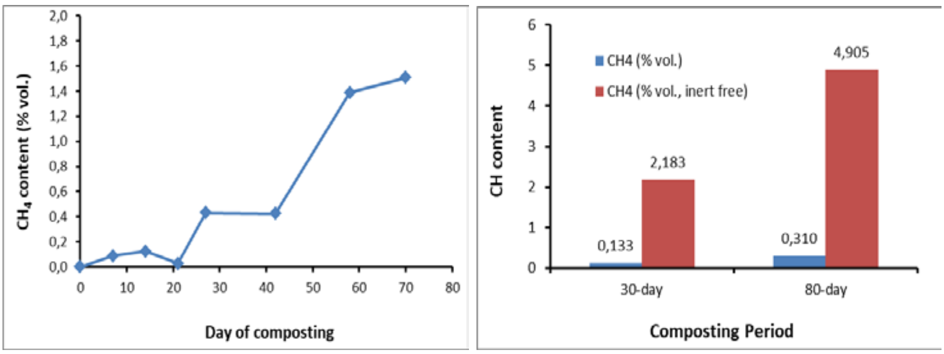

Fig. 4. Progress of methane content of gas emitted from composting pile (left), and average methane content for 30-day and 80-day composting period (right).

In this calculation we assumed that a fraction of carbon was evaporated in form of carbondioxide (CO_2) and methane (CH_4). Our measurement showed that CH_4 to CO_2 ratio in the gas was 2.18:97.82 and 4.90:95.10, respectively for composting periods of 30- and 80-day. The presence of methane indicated that anaerobic condition occurred in between of pile turning conducted every another day. Low content of CH_4 could be resulted from short period of anaerobic condition. Insufficient aeration can lead to anaerobic conditions due to the lack of oxygen, while excessive aeration can increase costs and slow down the composting process due to heat, water and ammonia losses (Jiang et al., 2015). The values of carbon, nitrogen, and hydrogen as presented in Table 1 were used to calculate the amount of gas emission from the piles during composting process.

3.2. Methane emission from composting piles

In order to evaluate methane emission reduction potential, first of all we have to calculate baseline (reference value) of methane emission from conventional ponds of WTP without composting process. This means that all POME was treated in the ponds and none of that is used for composting. The baseline methane emission ($CH_{4,B}$) was calculated from Eq. 5.

Using POME yield previously mentioned (0.803 m^3/ton FFB) and its COD value of 80.250 kg/m^3 (inlet) and 8.725 kg/m^3 (outlet) we have calculated baseline methane emission to be 13.611 kg CH_4/ton FFB. Using fraction of POME used for composting (*X*) of 43.18% and 78.04%, respectively for 30-day and 80-day composting period, it follows that methane emission reduction due to POME utilization for composting is 5.877 kg CH_4/ton FFB for 30-day and 10.622 kg CH_4/ton FFB for 80-day composting period. Methane emission resulted from composting piles is based on carbon balance (Eq. 1) and composition of gas emitted from the piles. The result is summarized in Fig. 5.

Using POME density of 0.9917 kg/liter, it follows that mass of POME (m_2) addition during composting was 219.58 and 396.91 ton for 30-day and 80-day composting period, respectively. Using mass balance (Eq. 1), the amount of gas emitted from the piles during composting is 14.61 ton and 19.87 ton for composting period 30 days and 80 days, respectively. Previously we have showed that methane gas emitted from piles for 30-day composting period composed of 2.18% CH_4 and 97.82% CO_2. From this number we can calculate the amount of CH_4 emitted from the composting pile ($CH_{4,P}$) to be 0.32 t C or 0.427 t CH_4 which is equivalent to 0.68 kg CH_4/ton FFB. Similarly, for 80-day composting period we have carbon gases emitted from piles as 19.87 t with 4.90% CH_4 and 95.10% CO_2. Methane emission from composting piles is calculated similarly and the result is 0.97 t C or 1.30 t CH_4 which is equivalent to 2.06 kg CH_4/ton FFB.

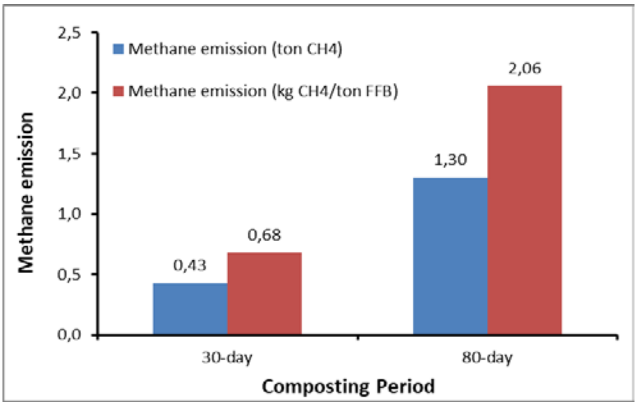

Fig. 5. Methane emission from composting pile for two different composting periods

3.3. Fossil fuel emission

During composting process, diesel fuel was used to operate trucks, backhoe loader, and turner machine. The use of diesel fuel eventually contributes to methane emission. Therefore we have to consider this fossil fuel utilization during composting operation as the emission source. Our observation revealed that consumption of diesel fuel for composting process was 0.097 l/ton FFB for 30-day composting period and 0.259 l/ton FFB for 80-day period. Factor emission for diesel agricultural equipment is 1.44 g CH_4/gallon or 0.38 g CH_4/l (EPA, 2016), which resulted in 0.301 kg CH_4/ton FFB for 30-day, and 1.3 kg CH_4/ton FFB for 80-day composting period.

3.4. Electricity emission

POME was sprayed over the EFB pile by using electrical pump of 40 hp. Our observation noted that POME spraying took two hours for each pile. This means total 24 hours pump utilization for 30-day composting period and 66 hours for 80-day. Using a pump with a power of 40 hp (≈30 kW), it comes that electricity energy consumption will be 0.72 MWh for 30-day composting period, and 1.98 MWh for 80-day. The electricity power in the POM is generated from biomass power plant. Methane is emmitted normally from incomplete combustion. Using methane emission factor of 0.0092 kg CH_4/MWh from biomas gasification power plant (Manuilova et al., 2016), it follows that methane emission due to electricity consumption for composting is 0.0066 kg CH_4 for 30-day period, and 0.0182 kg CH_4 for 80-day.

3.5. Total methane emission reduction

Methane gas emission reduction is calculated using Equation 4. Methane emission for each component was summarized in Fig. 6. It is revealed that methane **g**as emission reduction resulted from co-composting activity was 4.889 kg CH_4/ton FFB for 30-day composting period and 7.244 kg CH_4/ton FFB for 80-day. This means a reduction of 35.92% and 53.22% from the baseline value, respectively for 30-day and 80-day composting period. POME utilization for composting saves the biggest part of the total reduction.

It is important to note that treating POME using anaerobic digester facility will result in greater benefits: reducing methane emission while producing biogas energy. Typical POM with FFB capacity of 30 t/h may generate 0.7 MWe from POME-biogas (Sugiyono et al., 2019). Biogas technology application in POMs, however, is slow because of several reasons. Most POMs are already energy self sufficient based on electricity generated from solid waste (fiber and shell). In addition, the excess electricity from biogas is difficult to be distributed to main electricity network because of POM's position in remote areas. High investment is another reason for the slow application of the biogas digester in POMs.

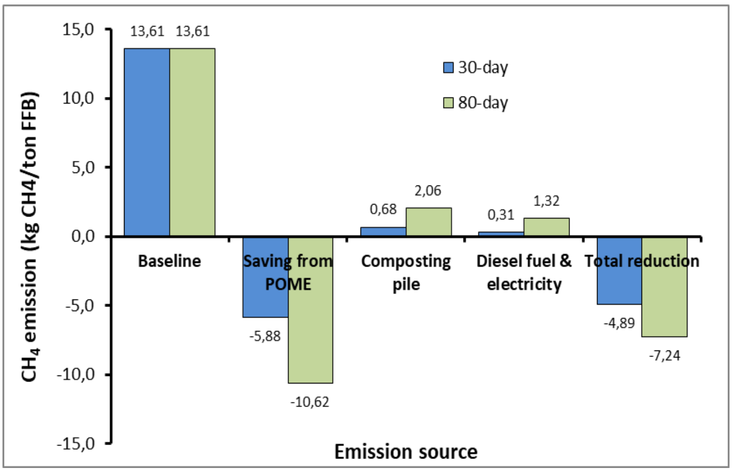

Fig. 6. Total methane emission reduction from co-composting of EFB and POME for 30-day and 80-day composting periods.

4. Concluding remarks

The use of POME for composting of EFB reduces methane emitted from POM. Open windrow co-composting EFB and POME is able to reduce methane emission by 4.889 kg CH_4 per ton of FFB or 35.92% for 30-day composting period. Extending composting period to 80-day increases methane emission reduction up to 7.244 kg CH_4 per ton FFB or 53.22% as compared to conventional POME treatment with no co-composting operation.

The magnitude of emission reduction depends on the fraction of POME used for composting process as well as composting period. This result implies that co-composting EFB and POME can be one way to reduce environmental burdens in POMs. Application of co-composting EFB dan POME will also increase sustainability of palm oil industries.

Acknowledgement
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Abbreviation list

CPO	: crude palm oil	POM	: palm oil mill
EFB	: empty fruit bunch	POME	: palm oil mill effluent
FFB	: fresh fruit bunch	WTP	: wastewater treatment plant

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