Emission Factor from Small Scale Tropical Peat Combustion

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Abstract. Peatfire in Indonesia recently had become an important issue regarding its global warming impact of green house gases emitted. Emission factor is one of important variables to determine total emission of carbon released by peatfire. But currently there were only a few studies about Indonesian peat fire emission factors. The previous studies of Indonesian peat fire emission factor reported the results from a very limited number of samples and during smoldering combustion stages only. Therefore this study attempts to quantify carbon dioxide (CO₂) and methane (CH₄) emission factors from laboratory peat combustion based on higher number of samples and taken both of combustion stages (flaming and smoldering) into consideration. Peats were sampled from five different districts in Pontianak, West Kalimantan. Ultimate analysis showed that pure peat composed of relatively high carbon content (52.85 – 59.43% dry basis). Laboratory experiments were carried out by burning small amount of peats in a mini furnace and measuring their CO₂ and CH₄ emission concentration during flaming and smoldering. CO₂, CO and CH₄ average emission factors and their related average MCE for flaming were found to be 2,088 ± 21 g/kg (n = 17), 3.104 ± 7.173 g/kg (n = 17), 0.143 ± 0.132 g/kg (n = 17) and 0.998 ± 0.005 (n = 17), respectively, while for smoldering were 1,831 ± 131 g/kg (n = 17), 138 ± 72 g/kg (n = 17), 17 ± 12 g/kg (n = 17) and 0.894 ± 0.055 g/kg (n = 17), respectively. This emission factors based on the laboratory combustion experiment can be conveniently used to estimate CO₂ and CH₄ emission from Indonesian peat fire. Equation models to correlate between MCE and emission factors for both flaming and smoldering were developed. MCE and CO₂ emission factor during flaming was relatively higher than smoldering. On the contrary, CO and CH₄ emission factors were relatively smaller during flaming than smoldering.

1. Introduction

Indonesia has the fourth largest peatland in the world after Russia, Canada and The United States of America [1]. It is also the largest tropical peatland in the world with a total area of about 21 million ha [2] of which about 14.9 million ha is located in Sumatra, Kalimantan and Papua [3]. Naturally peatland preserves large carbon which has lasted for thousands of years [1], but the destruction of
peatland caused by land clearing, drainage and fires that occur mostly in Sumatra and Kalimantan [4] lead to a large amount of carbon release [5].

Recently, Indonesian peat fire has become one of international issues relating to its transboundary pollutant and global warming impact of carbon emitted. Peatfire emits largest amount of carbon especially carbon dioxide (CO$_2$), carbon monoxide (CO) and methane (CH$_4$) to the atmosphere [6]. CO$_2$ and CH$_4$ are both primary greenhouse gases responsible for global warming, and CO is a primary gaseous pollutant. CH$_4$ and CO act together as a major precursor of atmospheric ozone, one of green house gases and also a major secondary gaseous pollutant that causes photochemical ozone, one of primary gaseous pollutants due to the draining of peatland in Indonesia emits about 58% of total global peatland emissions (excluding peat fires), while the peat fires in Indonesia in 1997 is estimated to emit carbon similar to 13 - 40% of annual global carbon emissions in 2002 from fossil fuel combustion [9]. National Green House Gases Inventory (NGHGI) reported by the Ministry of Environment (2010) [10] in Indonesia Second National Communication (SNC) stated that carbon emissions from peat fires in Indonesia in 2000 was about 13% of the total carbon emissions resulting from various sectors in Indonesia.

Based on IPCC emission inventory methods (2006) [11] emission factor is one of the important factors in determining the carbon emission estimation from peatland. However, current carbon emission estimations from peat fires in Indonesia were still reported using using default emission factors obtained from measurements for other areas or other fuels. This of course can increase the uncertainty of the carbon emission estimations. Therefore it is necessary to study emission factor relevant to local condition and also to develop model to predict carbon emission factor based on peat carbon content can be mapped in order to minimize the uncertainty of the results of the emission estimates.

Current research on emission factors from peat fires in Indonesia is still rarely performed. Emission factor measured by Christian et al. (2003) [6] is one of the most referenced studies of the carbon emissions estimation from peat fires in Indonesia although the measurement was only conducted with one sample peat only. Stockwell et al. (2014) [12] conducted laboratory measurements on peat combustion emission and calculated emission factors based on three samples measured. He also carried out in field measurements during large peat fire in Kalimantan in 2015 [13] and calculated emission factors based on thirty five samples measured. Both of the former researchers performed the measurements only during smoldering combustion stages and none considered the influence of the peat’s carbon content. The very limited number of samples led to unknown variability in the dependence of emission factors to the type of peat being measured, the measurement techniques and other influencing factors [14]. Furthermore, the emissions measured from the very limited number of samples to represent the very extensive Indonesian territory would extend the uncertainty of the estimation results. Saharjo et al. (2010) [15] conducted emissions measurements on a single maturity type of peat burned in the field where the samples were taken during three emission stages that were flaming, smoldering and glowing combustions. Agus et al. (2011) [16] explains that type of peat maturities (hemic, fibric and sapric) affect the peat’s carbon content and bulk density which are major factors in calculation of fuel load. While type of combustion stages (flaming, smoldering and glowing) determine the composition and amount of emissions produced from peat consumed during peat fire [17][6]. Therefore this study aims to conduct more comprehensive research on fire emissions factors.
with regard to the peat’s carbon content, type of combustion stages and also the number of samples that can represent local condition in Indonesia.

2. Method

Peat was sampled from five different regions in Pontianak, West Kalimantan as shown in Figure 1. Eijkelkamp peat sampler [18] was utilizing to obtain samples from different depths in order to have samples with different carbon contents. Samples were dried in the oven at 105 °C for 24 hours, then grounded and sieved to 100 mesh prior to carbon content analysis. Carbon content of peat was measured using ASTM D5373 method.

Samples used for the combustion experiment were dried naturally under the sun prior to combustion. A representative sample of dried peats (about 10 g) were combusted in a mini furnace as shown in Figure 2 and the gaseous emission products were investigated by instrumental method as shown in Table 1. Peat were combusted under no control experiments to duplicate peat fire condition as observed in Kalimantan during field study. Two type of combustion phases were observed, flaming and then followed by smoldering. Flaming was defined as a condition when flame is visually observed during combustion, while smoldering was flameless. Emission factor (EF) of carbon emitted by peat combustion in unit of g of compound emitted kg of dry mass burned can be calculated by assuming that majority of of carbon in biomass smoke (> 95%) is contained in CO₂, CO and CH₄ as shown in the equation (1) below [19]:

$$EF_X = F_c \times 1000 \left( \frac{g}{kg} \right) \times \frac{M_{Mx}}{12} \times \frac{\Delta C_X}{\Delta C_{CO_2} + \Delta C_{CO} + \Delta C_{CH_4}} \text{  (1)}$$

where $F_c$ is mass fraction of peat carbon content, $M_{Mx}$ is molar mass of compound X (g/mol); 12 is molar mass of karbon (g/mol), $\Delta C_i$ is the excess mass mixing ratio of compound for each spesies (mol/m³) that is concentration measured in the smoke substracted by background concentration. Modified combustion efficiency (MCE) is calculated as an approach to measure relative contributions of flaming and smoldering combustions by using the equation (2) below [6][12][13][17][19][20]:

$$MCE = \frac{\Delta C_{CO_2}}{\Delta C_{CO_2} + \Delta C_{CO}} \text{  (2)}$$

where $\Delta C_i$ is the excess mass mixing ratio of compound for each spesies (mol/m³) that is concentration measured in the smoke substracted by background concentration.

![Figure 1](image-url) Locations of peat sampling in Pontianak, West Kalimantan
Table 1 Method used to measure gaseous emission products of peat combustion

| Parameter                          | Instrument used                                                | Measurement Method                        |
|-----------------------------------|----------------------------------------------------------------|------------------------------------------|
| CO                                | Environmental Sensors CO-meter; model Z-500XP                   | Electrokimia                             |
|                                   | Vaisala CO2-meter, model MI70                                 | Non-dispersive infrared (NDIR)           |
| CO2                               | Vaisala CO2-probe, model GMP343                                | Gas Chromatograph                        |
| CH4                               | Hotwire anemometer merek Lutron model AM-4204                 | Thermal anemometry                       |
| Gas flowrate and temperature in   | 20 ml vial bottle                                              |                                         |
| the stack                         | Lutron barometer model MHB-382SD                               |                                         |
| Pressure and relative humidity    | IRtek thermometer, model IR-60                                | Infrared                                 |
| Location coordinate and altitude  | GPS                                                             |                                         |
| Peat temperature                  | IRtek thermometer, model IR-60                                |                                         |

Figure 2 Mini furnace used for peat combustion

3. Result and Discussion

It was found that based on carbon analysis of seventeen Pontianak peat samples carbon content had range of 52.85 to 59.43 % (dry basis) with average of 57.09 ± 2.20 % (dry basis). Carbon contents of three peat samples from Pulang Pisau, Central Kalimantan had similar average of carbon content to Pontianak peat samples i.e 57.93 ± 2.52 % (dry basis) [12]. One peat sample taken from Teluk Pilau, South Sumatera had slightly lower carbon content than Kalimantan’s i.e about 54.7% (dry basis) [6].

Emission factor and MCE produced by Pontianak peat samples combustion during flaming and smoldering stages were presented in Table 2. CO2, CO and CH4 average emission factors and their related average MCE for flaming were found to be 2,088 ± 21 g/kg (n = 17), 3.104 ± 7.173 g/kg (n = 17), 0.143 ± 0.132 g/kg (n = 17) and 0.998 ± 0.005 g/kg (n = 17), respectively, while for smoldering were 1,831 ± 131 g/kg (n = 17), 138 ± 72 g/kg (n = 17), 17 ± 12 g/kg (n = 17) and 0.894 ± 0.055 g/kg (n = 17), respectively. The average emission factors for peat combustion during the flaming stage were relatively small compared with the smoldering one. This is because the flaming combustion occurs at a high temperature greater than 580 °C, therefore produce more high oxidised compounds such as CO2 [21]. On the contrary, the average emission factors for CO and CH4 during the smoldering stage were relatively much higher compared to the flaming one. It was due to smoldering combustion occurs at lower temperatures less than 580 °C and lead to the production of low oxidised compounds such as CO and CH4 [21].
### Table 2. Emission factor for Pontianak peat combustion

| Combustion stages | EF CO₂ (g/kg) | EF CO (g/kg) | EF CH₄ (g/kg) | MCE       |
|-------------------|---------------|--------------|---------------|-----------|
|                   |               |              |               |           |
| Flaming           | 1938± 2374    | 0.002 ± 23.542| 0.014 ± 0.490| 0.982 ± 1.000 |
|                   | 2088 ± 2417²  | 3.104 ± 7.173 | 17e           |           |
|                   | 17d           |             |               |           |
| Smoldering         | 1558 ± 1998²  | 138 ± 44²   | 0.774 ± 0.988| 17e       |
|                   | 1831 ± 131²   | 170 ± 12²   | 0.894 ± 0.055|           |
|                   | 17e           |             |               |           |
|                   | 17e           |             |               |           |
| Smoldering²        | 1637 ± 204²   | 233 ± 72²   | 17e           |           |
|                   | 3³            |             |               |           |
|                   | 3³            |             |               |           |

Superscript a = minimum, b = maximum, c = average, d = standard deviation, e = number of sample

EF = Emission factor, MCE = Modified Combustion Efficiency

Source: 1 Christian et al., 2003; 2 Stockwell et al. (2014)

Emission factor from laboratory scale of smoldering combustion from studies of Stockwell et al. (2014) [12] and Christian et al. (2003) [6] were shown in Table 2. Emission factors from three peat samples taken from the Mega Rice Project area in Central Kalimantan for CO₂, CO and CH₄ were 1637 ± 204 g/kg (dry basis), 233 ± 72 g/kg (dry basis) and 12.80 ± 6.6 g/kg (dry basis). The average MCE was 0.816 ± 0.065 [2]. Combustion of one peat sample taken from Teluk Pulau, South Sumatera had average CO₂, CO and CH₄ emission factors of 1703 g/kg (dry basis), 210.3 g/kg (dry basis) and 20.80 g/kg (dry basis) [6]. One-sample t test two-way with a significance level (α) = 0.05 and assuming normally distributed data was conducted to compare the average emission factors for smoldering stage in this study with others study performed by Stockwell et al. (2014) [12] and Christian et al. (2003) [6] for Pontianak, Pulang Pisau and Teluk Pulau peats, respectively. Hypothesis were:

H₀: There is no significance difference between the average emission factors resulted from the smoldering combustion in this study and others’.

H₁: There is significance difference between the average emission factors resulted from the smoldering combustion in this study and others’.

Testing criteria:
- Based on the value of t
  - If \(|t_{calculated}| \leq t_{critical}\) then H₀ is accepted
  - If \(|t_{calculated}| \geq t_{critical}\) then H₀ is rejected
- Based on the significance (p)
  - If \(p > 0.05\) then H₀ is accepted
  - If \(p \leq 0.05\) then H₀ is rejected

Table 3 presents the results of a one-sample t test for CO₂ and CO emission factors for smoldering stage where \(t_{calculated} > t_{critical}\) (p <0.05) so that H₀ is rejected and it could be concluded that there was significant difference between the average emission factors of CO₂ and CO values measured for peat combustion in this study and others [6][12]. This difference was due to higher MCE value measured for smoldering combustion in this study than others that lead to higher CO₂ but lower CO emission factors obtained in this study than others.
Tabel 3. One-sample t test results for smoldering emission factor

| Emission factor CO₂ | Degree of freedom (df) | t calculated | t critical | Test value | p (two way) |
|---------------------|------------------------|--------------|------------|------------|-------------|
| Emission factor CO  | 16                     | 6.098        | 4.014      | 1637       | 0.000       |
| Emission factor CO  | 5.462                  | 2.12         | 1703       | 0.001      |
|                     | 7.957                  |              | 210.3      | 0.000      |

Graph of simple linear regression between MCE and CO emission factors during flaming stage are presented in Figure 3. The linear regression equation obtained during flaming condition was: \( Y = -1705.2X + 1705.1; \ R^2 = 0.9991 \ (p = 0.000) \), where Y is CO emission factor (g/kg) and X is the MCE. From the graph it can be seen that the higher the MCE value lead to higher combustion efficiency and more complete combustion therefore resulting in lower CO emissions.

![Figure 3](image1.png)

Figure 3. A simple linear regression between MCE and CO emission factor during flaming stage.

Graph of simple linear regression between MCE, CO₂ and CO emissions factors during smoldering stage was presented in Figure 4a. The linear regression equation obtained for smoldering stage was: \( Y = 1928.8X + 106.05; \ R^2 = 0.6483 \ (p = 0.000) \); and where Y is the CO₂ emission factor (g/kg) and X is the MCE. The higher the MCE, the higher combustion efficiency and more complete the combustion was therefore resulting in higher CO₂ emissions.

Graph of simple linear regression between MCE and CO emission factors during smoldering stage was presented in Figure 4b. The linear regression equation obtained during smoldering stage was: \( Y = -1302X +1302.3; \ R^2 = 0.9907 \ (p = 0.000) \), where Y was CO emission factor (g/kg) and X was the MCE. The higher the MCE, the higher combustion efficiency and more complete the combustion was therefore resulting in lower CO emissions.

![Figure 4](image2.png)

Figure 4. A simple linear regression between MCE and a) CO₂ and b) CO emission factors during smoldering stage.
4. Conclusion
Laboratory scale of peat combustion in this study used higher number of peat samples (n = 17) compared to previous ones. The average emission factor obtained from larger number of samples in this study can improved the previous one obtained by others. It was found that the higher the MCE therefore the higher CO$_2$ emission factor was. On the contrary, the higher the MCE, the lower CO emission factor was.

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