Smoldering combustion propagation of subtropic peat; case study on pelalawan peat

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Abstract. Smoldering combustion was categorized as a very dangerous combustion and considered as a main cause to haze problem during wildland fires in Sumatera, Indonesia. This study aims to determine the characterized of the spread of peat fire, so the mitigation can be done. This study was used experimental methods. In this case, peat from Riau were analyzed and the samples to be used were peat that has been dried in the oven during 24 hours at 100 °C of temperature, moisture content after interaction with air was 7.09%. This study was resulted the maximum combustion temperature of 508.72 °C. The rate of propagation of peat fires was determine from the difference of time when the combustion temperature reaches 300 oC and 365oC. The rate of smoldering propagation at temperature of 300oC of 14.3 cm/h on the vertical direction and 6.31 cm/h on horizontal direction. The rate of smoldering propagation at temperature of 365°C of 19.76 cm/h on the vertical direction and 5.17 cm/h on horizontal direction.

1. Introduction

Fire on peatlands is a very dangerous fire, which produced high toxic emission. Most of peat fires were caused by large-scale of land reveal and canal establishment of peatlands, which can damage the physical and chemical properties of the peat and affect the decrease in moisture content, until the peat becomes dry, especially in the dry season. Dry peat will be highly flammable and peatland fires can be dominated by self-sustained combustion, slow-moving of propagation and low temperatures [1]. Indonesia has the largest peatland among tropical countries. Fires in Indonesia in 2006 was 2.79 million hectares of peatland had been emission 98.38-180.38 million tons of CO2 [2]. In 2015 Badan Nasional Penanggulangan Bencana (BNPB) estimates that total of burned areas in Indonesia of 2,089,911 ha and 618,574 ha from peatlands. It can hamper national action plans to reduce greenhouse gas emissions to 26% in 2020, if peatlands continue to burn on a large scale [3].

Indonesia has the largest peatland among tropical countries. The area of peatland in Indonesia reaches 20.6 million ha or 10.8% of the land in Indonesia. The largest peatland was located in the island of Sumatra which is 6.4 million hectares, which is spread in some provinces. One of the largest peatlands in Sumatera is Province of Riau, where 3.8 million hectares were scattered in some districts, where Pelalawan Regency is the region with the third largest peatland after Indragiri Hilir and Bengkalis [4]. The extent of peatlands in Riau, especially in Pelalawan District, is at risk for peat fires, and can lead to greenhouse gases, disrupt the balance of ecosystems, and contribute to financial losses, especially in Riau.

Initial research regarding smoldering combustion was first published in 1957. Palmer, conducted an experiment of smoldering combustion in dust and fibrous materials [5]. Smoldering combustion occurs at low-temperature, and generates incomplete combustion. Therefore, smoldering combustion produced toxic gases and particulates at a higher rate than flaming combustion. Palamba, P., was conducted a study of smoldering combustion analysis on dry peat in two different locations. Samples...
were taken from Ogan Komering ilir (OKI), South Sumatera Province, and from Kampung Bagaiserwar, Sarmi Regency, and Papua Province. In general, there are three main stages of smoldering combustion namely, heating, combustion (consisting of pyrolysis and oxidation), and charcoal or ash formation [6]. This study aims to determine the comparison of the characteristics of burning of peat from Ogan Komering Ilir (OKI), South Sumatera Province and Kampung Bagaiserwar, Sarmi Regency, Papua Province.

The purpose of this study is to find out the propagation characteristics of peat fires, so that mitigation of peat fires can be done.

2. Methodology
In this study, we used the experimental method. The sample that used was peat from province of Riau. Sampling technique using a systematic random. The method used for sample collection is an uninterrupted method, so the nature of the sample does not change and it was not affected by microbial activity until the experimental work time.

2.1 Experimental Setup

2.2 Experimental Preparation
The experimental apparatus that was used in this experiment can be shown in Figure 2, whereas reactor of 100x100mm was used for sample and digital weighing were equipped to measure mass loss of peat sample [7]. To reduce the waste heat that generated from combustion, this experiment equipment was designed using heat resistant calci boards. In other side, the reactor was perforated to insert nine thermocouples as a temperature gauge, thus the overall distribution in the combustion chamber will be measurable and will be converted in figures by a DAQ system connected to personal computer. Each thermocouple was set of 2.5 cm to another. So, the speed of propagation of combustion can be calculated by comparing the distance between the thermocouple with the difference of time between the thermocouple, when the burning temperature reaches 300 °C and 365 °C.
2.3. Moisture Content

The moisture content on a dry basis is a percentage equivalent to the ratio of water weight to dry material weight \[8\]. Water content (moisture content) on dry basis, obtained by using the following formula:

\[
MC = \frac{m_1 - m_2}{m_2} \times 100\%
\]

Dimana :

\( MC \) : Moisture Content (%)
\( m_1 \) : initial mass (gram)
\( m_2 \) : final mass (gram)

After testing and processing the data, moisture content from peat can be seen in Table 2.

### Table 1. Moisture Content

| \( m_2 \) | \( m_1 \) | Moisture Content (% dry base) |
|----------|----------|------------------------------|
| 0.202    | 2.002    | 891.089                      |

By following sample preparation and sample drying procedures, the average moisture content of Pelalawan Regency was reached 891.089%.

2.4 Experimental Procedure

The peat samples were dried by using an electric oven, in accordance to ASTM standard \[9\] peat was dried at 100°C during 24 hours, the heating coil was connected to the reactor. Data acquisition systems and mass-change readings connected to laptop. Then the thermocouple was calibrated before the experiment was done and press the zero button on the scales, before the peat was filled up in the reactor to measure the initial mass and the final mass during the experiment. The heater (coil heater) was switched on for 45 minutes and considered heat heating energy was able to sustain peat burning until the peat can burn by itself.

2.5. Data Collecting

2.5.1. Physical Characteristics

Physical characteristics of Pelalawan peat are shown by Table 1. Pelalawan peatlands can be classified (ASTM D4227-13) as peat with moderate ash content (5-15%) and Hemic (33-67%) or Semi Fibrous.
Table 2. Physical Characteristics of Pelalawan Peat

| Physical Characteristics | Unit      | Value |
|--------------------------|-----------|-------|
| Density                  | Kg/m³     | 1.5   |
| Wet Volume weight        | ton/m³    | 1.1   |
| Dry volume weight        | ton/m³    | 0.1   |
| Porosity                 | %         | 92    |
| Ash Content              | %         | 6.3   |
| Organic Content          | %         | 94    |
| Fibre Content            | %         | 44    |
| Electric Resistance      | Ohm meter | 12    |

2.5.2. Higher Heating Value
The calorific value is sought to determine the amount of heat present in peat per gram. Heat value obtained from the test using the Digital Bomb Calorimeter C-200 tool, where the data obtained in the form of temperature rise. Temperature rise from Pelalawan peat samples is 1.71 with 1 gram peat mass. Until the HHV value is obtained by using the formula as follows:

\[
HHV = \frac{\text{Temperature rise} \times 2332}{\text{weight}}
\]

HHV = 3987.72 caloric/gram

3. Result and discussion

3.1 Result

3.1.1 Propagation Smoldering Combustion of Peat

a. Smoldering Propagation Rate on Vertical Direction

Smoldering combustion propagation on vertical direction got from the distance between the thermocouple divided by the time difference in each thermocouple when the combustion temperature reaches 300°C and 365°C. Smoldering combustion propagation of thermocouple 1 (Th1) to thermocouple 4 (Th4) is v1, and v2 is the burning burning of thermocouple 4 (Th4) to thermocouple 7 (Th7), and so on which can be seen in the burning propagation scheme Figure 3.
Figure 3. Vertical Direction Propagation Scheme

From the time difference obtained between the thermocouples when the combustion temperature reaches 300°C, the velocity of smoldering combustion on the vertical direction in each thermocouple, which can be seen in Table 3.

| Table 3. Smoldering Propagation Rate |
|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| v1 (cm/jam) | v2 (cm/jam) | v3 (cm/jam) | v4 (cm/jam) | v5 (cm/jam) | v6 (cm/jam) |
| 1.3 | 26.6 | 15.6 | 3.9 | 14.1 | 24.2 |

The mean speed of smoldering combustion propagation in the vertical direction is as follows:

$$v_{\text{average}} = \frac{v_1 + v_2 + v_3 + v_4 + v_5 + v_6}{6}$$

$$v_{\text{average}} = 14.3 \text{ cm/h}$$

From the time difference obtained between the thermocouples when the combustion temperature reaches 365°C, the velocity of smoldering combustion on the vertical direction in each thermocouple, which can be seen in Table 4.

| Table 4. Smoldering Propagation Rate |
|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| v1 (cm/jam) | v2 (cm/jam) | v3 (cm/jam) | v4 (cm/jam) | v5 (cm/jam) | v6 (cm/jam) |
| 57.325 | 8.867 | 16.886 | 1.061 | 23.316 | 11.097 |

The mean speed of smoldering combustion propagation in the vertical direction is as follows:

$$v_{\text{average}} = \frac{v_1 + v_2 + v_3 + v_4 + v_5 + v_6}{6}$$

$$v_{\text{average}} = 19.76 \text{ cm/h}$$

b. Smoldering Propagation Rate On Horizontal Direction

Smoldering combustion propagation on vertical direction is get from the distance between the thermocouple divided by the time difference in each thermocouple when the combustion temperature reaches 300°C and 365°C. Smoldering combustion propagation of thermocouple 1 (Th1) to thermocouple 2 (Th2) is v1, and v2 is the burning burning of thermocouple 2 (Th2) to thermocouple 3 (Th3), and so on which can be seen in the burning propagation scheme of Figure 4.
From the time difference obtained between the thermocouples when the combustion temperature reaches 300°C, the velocity of smoldering combustion on the vertical direction in each thermocouple, which can be seen in Table 5.

### Table 5. Smoldering Propagation Rate

|   | v1 | v2 | v3 | v4 | v5 | v6   |
|---|----|----|----|----|----|------|
|   | 0.81 | 14.8 | 2.03 | 10.6 | 1.48 | 8.09 |

The mean speed of smoldering combustion propagation in the vertical direction is as follows.

\[ v_{\text{average}} = \frac{v_1 + v_2 + v_3 + v_4 + v_5 + v_6}{6} \]

\[ v_{\text{average}} = 6.31 \text{ cm/jam} \]

From the time difference obtained between the thermocouples when the combustion temperature reaches 365°C, the velocity of smoldering combustion on the vertical direction in each thermocouple, which can be seen in Table 6.

### Table 6 Smoldering Propagation Rate

|   | v1 (cm/jam) | v2 (cm/jam) | v3 (cm/jam) | v4 (cm/jam) | v5 (cm/jam) | v6 (cm/jam) |
|---|-------------|-------------|-------------|-------------|-------------|-------------|
|   | 1.211       | 5.806       | 1.046       | 8.427       | 0.539       | 13.997      |

The mean speed of smoldering combustion propagation in the vertical direction is as follows.

\[ v_{\text{average}} = \frac{v_1 + v_2 + v_3 + v_4 + v_5 + v_6}{6} \]

\[ v_{\text{average}} = 5.17 \text{ cm/jam} \]

#### 3.1.2 Mass Loss Rate

Before getting mass loss rate, then first look for mass loss from result of burning that have been done. Mass loss is obtained from the following formula:
Mass loss = initial mass - final mass
= 217 gram

Burning time up to extinguish for 16 hours. Until the mass loss rate (m) is obtained:

\[ m = \frac{\text{massloss}}{\text{time}} = 13.56 \text{gram / h} \]

3.1.3 Emissions from Peat Burning

In this research, to get the emission of gas from the result of peat burning using technomotor test equipment. The average exhaust emissions from combustion in peat obtained from technomotor, with CO emissions of 0.078% and CO2 of 0.214%. CO and CO2 emissions test is carried out for 106 seconds, then scaled during combustion, ie for 16 hours and multiplied by mass loss rate, then CO gas percentage is obtained from 1.06% and CO2 gas 2.9%.

![Figure 5. Graph of CO and CO2 Emissions on Peat Fires](image)

3.2 Discussion

From Figure 6 can be seen changes in fluctuating temperature, when the heating coil is turned off then the temperature will decrease drastically, but eventually the temperature will increase again. This is because the smoldering propagation occurs outside the boundary of the reading system of the thermocouple and has not yet reached the limit of the other thermocouple readings. Combustion experiment in this study is a shallow burning, since combustion occurs only <2m [10].

![Figure 6. Profile of Temperature Changes and Mass Loss from Peat.](image)
The maximum temperature of smoldering combustion is 508.72ºC, when burning lasted for 8.3 hours. The combustion takes place for 16 hours, where on the heating coil is placed close to thermocouple 6 (T6) with its maximum temperature reaching 600ºC. The initial propagation is more dominantly upward by seeing the high temperature in thermocouple 3 (T6) is 462 ºC compared to thermocouple 9 is 400 ºC at 45 minutes burning time, this is because more oxygen or air in the upper peat (thermocouples 1,2 and 3) than the bottom peat (thermocouples 7, 8 and 9). The upper peat more rapidly loses mass, which can be seen in Figure 6. Where the combustion time for 8.8 hours the average temperature on thermocouples 1, 2 and 3 reaches 72°C, which is close to unburned temperatures. This is due to the subsidence of vacancies from the center and bottom of the burning peat.

4. Conclusion
The rate of smoldering propagation on a temperature of 300ºC is 14.3 cm/h on the vertical direction and 6.31 cm/h on horizontal direction. The rate of smoldering propagation on a temperature of 365ºC is 19.76 cm/h on the vertical direction and 5.17 cm/h on horizontal direction. The rate of propagation of combustion on the vertical and horizontal combustion direction is constantly changing. This is caused by an ever-changing burning temperature and will automatically affect the burning speed. The higher the combustion temperature then the burning propagation rate will increase.

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