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Observation of Horizontal Smouldering Spread on Layer Thickness of Tropical Peat

Hafizha Mulyasih; Randitia Andika Putra; Bintang Farhan Muhammad[1]; Ridho Irwansyah[1]; Yulianto Sulistyo Nugroho*[1]

Department of Mechanical Engineering, Universitas Indonesia, Kampus UI Depok 16424, Indonesia
{hafizha.mulyasih, bintang.farhan, ridho.irwansyah04, yulianto.nugroho}@ui.ac.id,
{randitia.andika@alumni.ui.ac.id}

**Corresponding author*

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Abstract

Smouldering spread of peat fires has been studied by numerous researchers. Experimental work was performed to study the impact of peat layer thickness on horizontal smouldering spread behaviour. The thickness of the peat layer was varied 2 cm, 3 cm, and 4 cm peat thickness. A 3 cm-long coil heater was placed in the centre of the base. For ignition protocol, the coil heater was powered with 100 W of electricity for the first 60 minutes. Smouldering behaviour was observed by the temperature data, that measured using thermocouples and a thermal camera. The thickness of the peat layer and bulk density play important roles in the horizontal spread probability, as it changes the heat balance between the heat generation at the reaction zone and heat loss to the environment. Higher peak temperature was observed for peat 4 cm depth and then decreased by the thickness. The smoldering spread rate increases by peat thickness from 2.01 cm/h to 2.21 cm/h and then reach an asymptotic level. Extinction corresponds to a negative energy balance observed in thickness 2 cm of peat. A self-sustained smoldering front could not be maintained after the igniter was turned off.

1. Introduction

Peat fires remain a serious environmental problem on a global scale (Stracher *et al*. 2015). It releases a large amount of carbon into the atmosphere and causes significant damage to peatland ecology and the landscape (Usup *et al.* 2004). When ignited, peat fires can produce a thick smoke that reduces visibility and causes several health problems. Reduction of peat fire probability has been a high priority through peatland restoration and better early warning systems for the development of fire hotspots.

Peat is a transitional organic soil from plant matter to coal with a high carbon content (Roy *et al.* 1983), consisting of a porous structure that causes smouldering combustion dominated when it burns (Rein 2009). Smouldering combustion is a phenomenon with low temperature and slow propagation characteristics. Ohlemiller (2002) and Rein *et al.* (2009) explained in general that smouldering has four stages while it is spreading: the preheat zone, the evaporation zone, the decomposition zone, and the char-oxidation zone. Zanoni et al. (2018) pointed out that all phenomena in smouldering combustion affect the burning object's energy balance, suggesting a local and global energy balance (Zanoni *et al.* 2018). For the smouldering experiment, the energy balance could be represented by the flow of $\dot{E}in$ as the energy provided by the heater; $\dot{E}oxid$ as the energy released by the oxidation process; $\dot{E}pyr$ as the energy absorbed by the pyrolysis process; $\dot{E}evp$ as the energy absorbed by the water evaporation process; $\dot{E}out$ as the energy removed by the convective gas flow out; and, $\dot{E}loss$ as the energy removed by radial heat loss. Therefore, the net energy rate is:

$$\dot{E}net = \dot{E}in + \dot{E}oxid + \dot{E}pyr + \dot{E}evp + \dot{E}out + \dot{E}loss \quad (1)$$

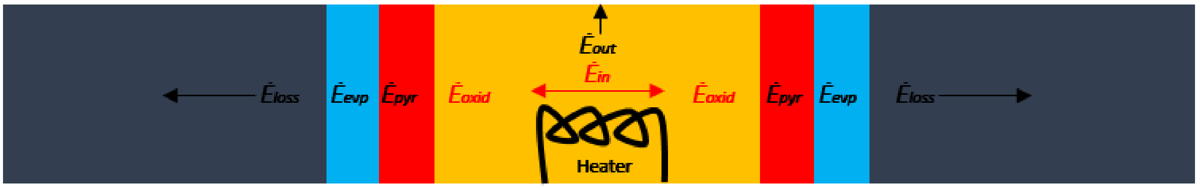


Figure 1- Conceptual model of Horizontal Smouldering Spread

Several studies have been reported before, that includes the upward and downward peat smouldering (Huang and Rein 2018) and the investigation of smouldering combustion propagation of dried peat (Palamba *et al.* 2017). In another work, the results of a modelling work by Huang and Rein (Huang and Rein 2015) reveal that smouldering combustion can spread over peat layers with very high moisture content (>250%) if the layer is thin and located below a thick drier layer. Christensen et al. (Christensen *et al*. 2020) was conducted a novel approach combining lateral and in-depth spread rates as vector components. The questions arise regarding the influence of peat layer thickness from one area to another. This is a challenge whether ignition can occur on peat with different thicknesses. In its natural stage, even though the peat layer is deep and covered by water, as soon as the rainy season is over, the draining process in the upper layer of the peat (1-5 cm) may create a dry surface that is vulnerable to catch fire. In addition, it is still rarely found research that discusses the spread that occurs horizontally on thin layers of tropical peat. This study extends earlier work on the horizontal smouldering spread of a peat sample from Papua, Indonesia (Putra *et al*. 2020). Samples and methods were changed so that the impact of density and peat structure on the phenomenon could be better explained.

2. Experimental Methods

2.1. Peat sample preparations

The peat samples came from the Palangka Raya, Indonesia, with coordinates N: 02°17'21.5412"; E: 114°1'58.492", and called PKY. The results of the Proximate and Ultimate (Table 1), are used to find out the difference in the physical characteristics and chemical components that affect the combustion process. Higher volatile matter, oxygen concentration, and lower bulk density could accelerate the smouldering spread, while ash content and moisture content tend to slow down the smouldering spread. A higher calorific value could produce greater heat energy when the sample is burned.

The PKY was dried in an electric oven at 100 °C within 24 hours until the peat samples' moisture was ~ 8%. Scanning electron microscope tests are also carried out to determine the structure and pore sizes of the peat samples. Figure 2b shows that the pore size for PKY is approximately 2.5 µm. This porosity value can affect the drying and combustion reaction processes.

Table 1- Proximate and Ultimate Analysis of Peat Samples

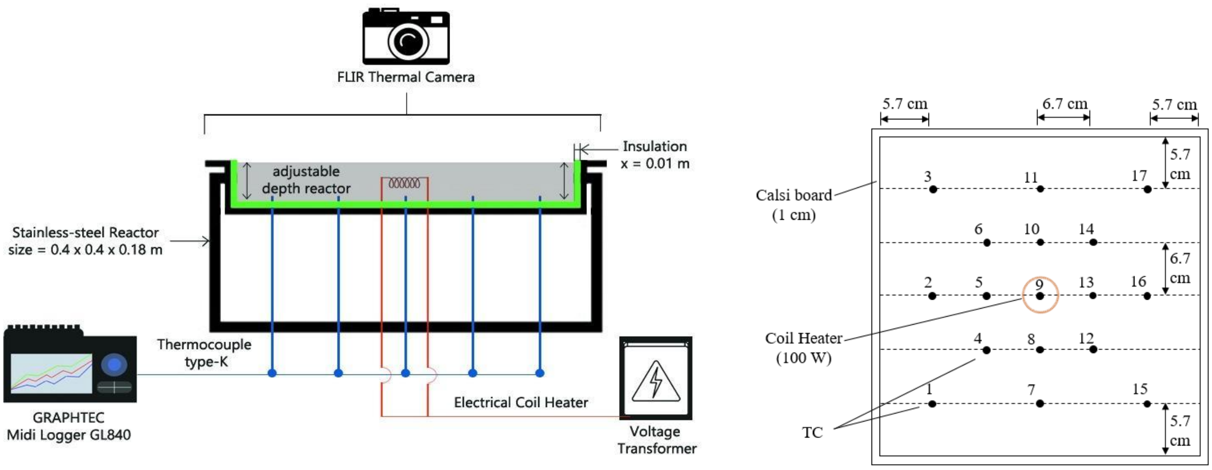
Proximate Analysis		Ultimate Analysis	
Initial Moisture (%)	69.20	C (%)	57.43
Moisture in as-dry based (%)	8.20	H (%)	4.80
Ash (%)	7.50	N (%)	1.10
Volatile Matter (%)	49.80	O (%)	29.01
Fixed Carbon (%)	34.50	Total Sulphur (%)	0.10
Gross Calorific Value (MJ/kg)	4930	Bulk Density (kg/m^3)	360

(a) (b)

Figure 2- (a) PKY before the combustion process, (b) Scanning electron microscope result of PKY.

2.2. Smouldering experiments procedure

The adjustable reactor was developed to conduct the smouldering experiment. It is made of stainless steel measuring 40 × 40 cm isolated by 10 mm thick calcium-silicate board insulation around the reactor side and on the bottom of the reactor. The reactor was designed with an adjustable base so that it can be used for a variety of peat thicknesses. This work investigated the horizontal spread on 4 cm, 3 cm, and 2 cm peat layer thickness. For the ignition protocol, a three cm-long coil heat igniter was placed at the centre of the base and was powered with 100 W of electricity for 60 min. This ignition protocol follows previous work (Putra *et al*. 2020). After the igniter was turned off, the combustion process was self-sustaining smouldering. The seventeen thermocouples (Figure 3b) were inserted from the bottom side and measured using a Graphtec GL840 data logger. The thermocouple tip was located at a depth of 1 cm from the reactor base. The peat samples' mass was weighed before and after the experiment to determine the mass reduction caused by combustion. The experiments were repeated twice on each peat thickness.



(a) (b)

Figure 3- Experimental setup. (a) Device arrangement, (b) Thermocouple arrays.

2.3. Image Analysis Tools

The thermal camera used in this experiment was a FLIR A35x with a resolution of 320 x 256 pixels, temperature range from 50 ˚C to 550 ˚C with accuracy ± 5 ˚C or 5% of reading. The images were taken every 10 minutes after the ignition started. The infrared camera was placed at a distance of 100 cm with angles of 20˚ from the peat surface to avoid getting too hot from the burning peat. The images obtained from thermal cameras represented the temperature that occurred on the peat surface. In general, every image consists of RGB colour in its pixels. These three colour component combinations will create a specific colour for its pixel. To determine the value of spread rate, two pictures with different time taken were compared. To do this image processing needs to be done on thermal images. Many authors have suggested this method for different scales of application (Stracher *et al.* 2015, Putra *et al.* 2020, Burke *et al*. 2019, Bhattacharjee *et al.* 2017, Christensen *et al.* 2018).

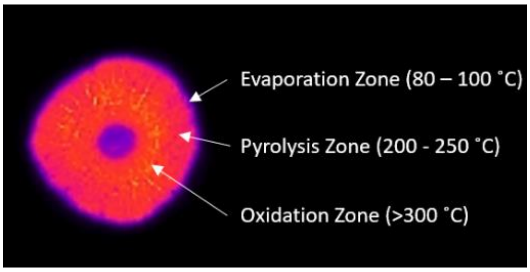


Figure 4- Different zones when the peat combustion process occurs

3. Results and Discussion

3.1. Infrared Images Results

Smouldering on peat with a thickness of 4 cm and 3 cm managed to spread to the side of the reactor, while peat with a thickness of 2 cm failed to sustained-smouldering because it went out shortly after the igniter was turned off. Smouldering fire on peat with a thickness of 4 cm has high sustainability. These caused by the heat generated by the peat fire is higher than heat loss to the environment and to the peat itself for the drying process and pyrolysis process. Therefore the smouldering process will continue until the heat generated could not equilibrate the heat loss. On the thinner thickness of 2 cm on PKY shown in Figure 5c, the smouldering fire did not sustain after the igniter was turned off. This proves that the heat generated by the peat is smaller than the heat loss to the environment (Huang and Rein 2018). This process also happened on Papua peat with a thickness of 2 cm from previous work (Putra *et al.* 2020).

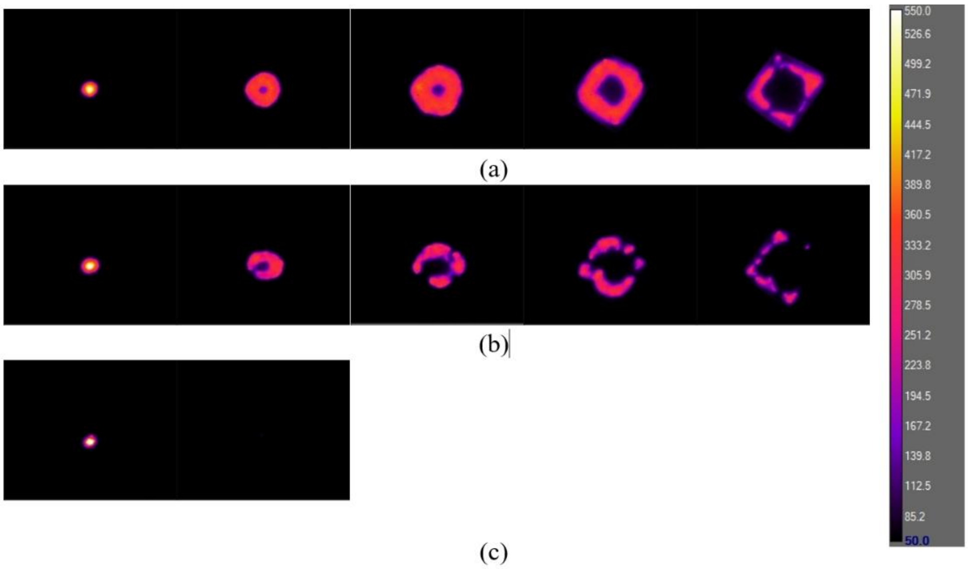


Figure 5- Horizontal Smouldering Spread from PKY Peat: (a) 4 cm thickness, (b) 3 cm thickness, (c) 2 cm thickness. The time between each picture is 2 hours.

3.2. Temperature Profile of Smouldering Peat

Differences were also found in the results of temperature measurements obtained from thermocouple measurements (Figure 6). Moreover, the difference in bulk density and homogeneity can be explained by Figure 7. In this case, peat samples were sieved using a 6 mm wire mesh size. With the sieving process, it is expected that peat approaches closer to more homogeneous conditions in terms of peat grain size. The first sieved peat shows a more regular temperature pattern compared to the un-sieved one. The regularity of this pattern is also seen in images captured by infrared cameras (Figure 8), where the sieved peat has better homogeneity so that the distribution of heat also occurs more evenly. Different peat grain sizes cause cavities in several areas in the reactor, making a difference in oxygen supply so that the spread becomes less consistent. Whereas on peat that is not sieved, its distribution is often irregular. Sometimes, it suddenly experiences a drastic increase in temperature while in an area with a better fuel and oxygen supply mixture. Peak temperature also differs between sieved and un-sieved peat samples. This is due to the sieved peat sample having a higher bulk density so that the surface area of the peat that experiences a combustion reaction is also greater, causing a higher peak temperature. Table 4 shows the bulk density values of the sieved and un-sieved peat samples used in this study. There are significant differences in the bulk density values of the two peat samples. For un-sieved peat samples, the average bulk density used for the experiment is 278.79 ± 1.4 kg/m^3. After the sieving process, the average bulk density was increased to 299 ± 4.4 kg/m^3. The difference in bulk density values can be seen visibly from peat after being drained, whereas the un-sieved peat tends to be more porous compared to the sieved peat. Lower bulk density causes a faster spread of horizontal smouldering. The cavity between macros between one and another provides a pathway for oxygen to enter, thus accelerating the combustion reaction rate.

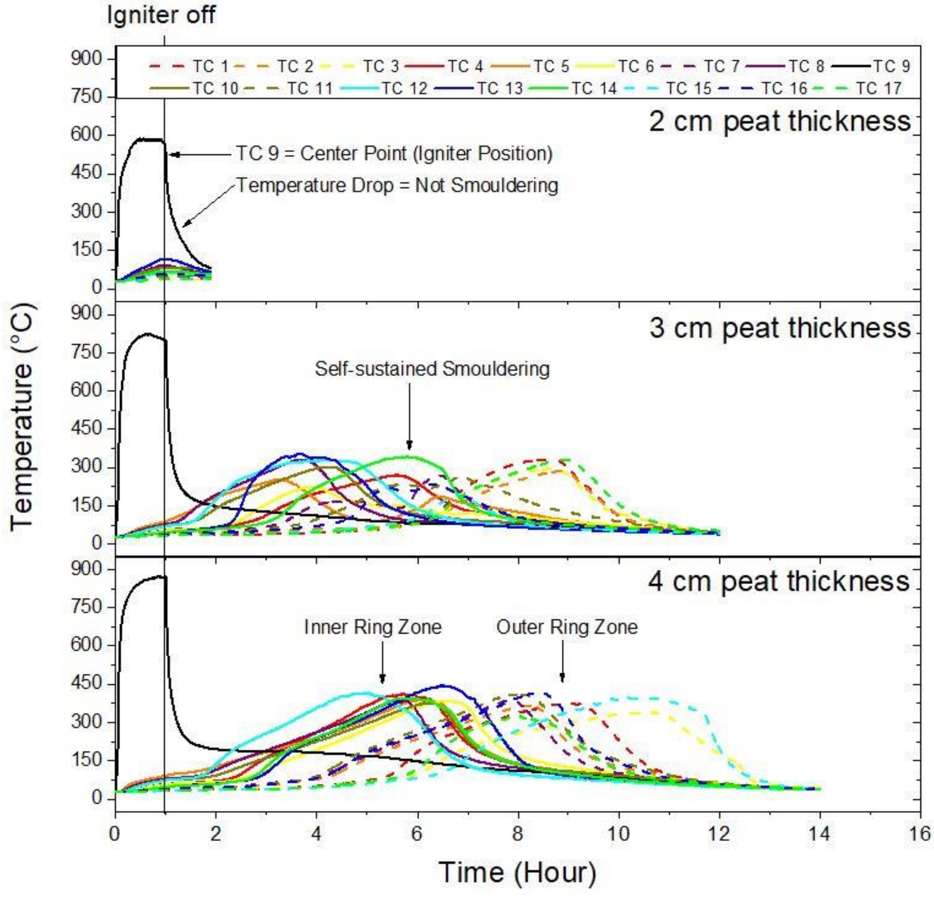
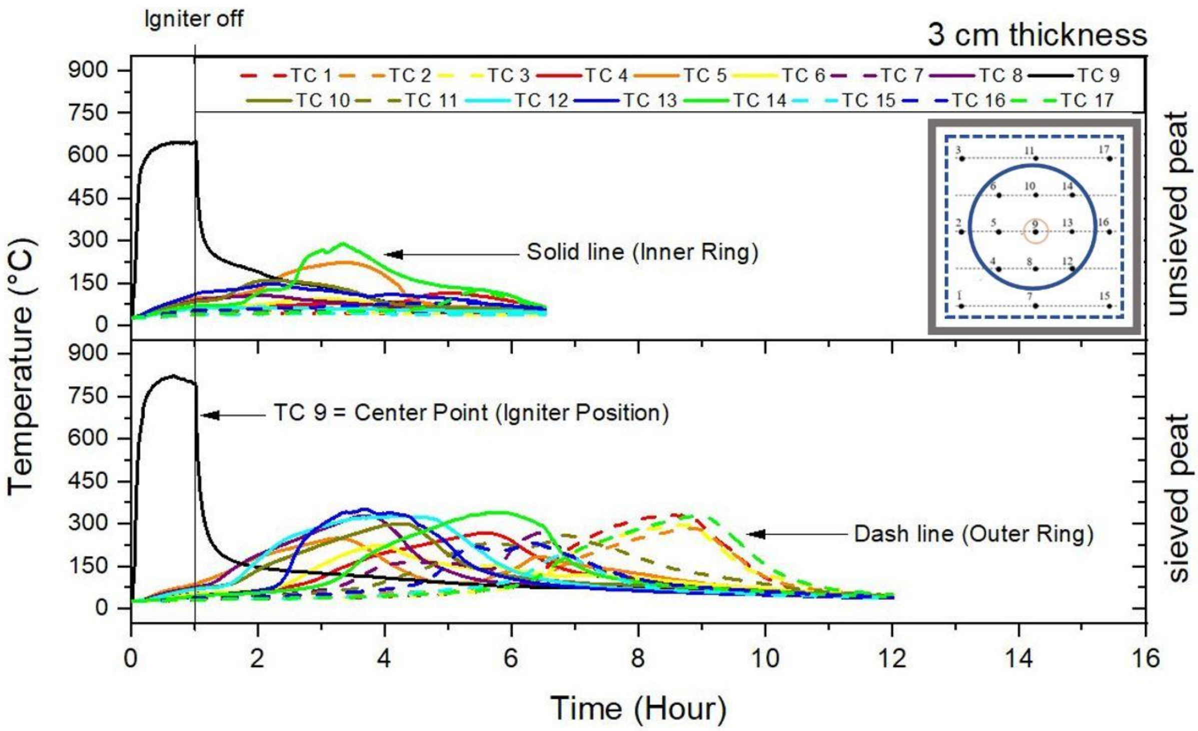
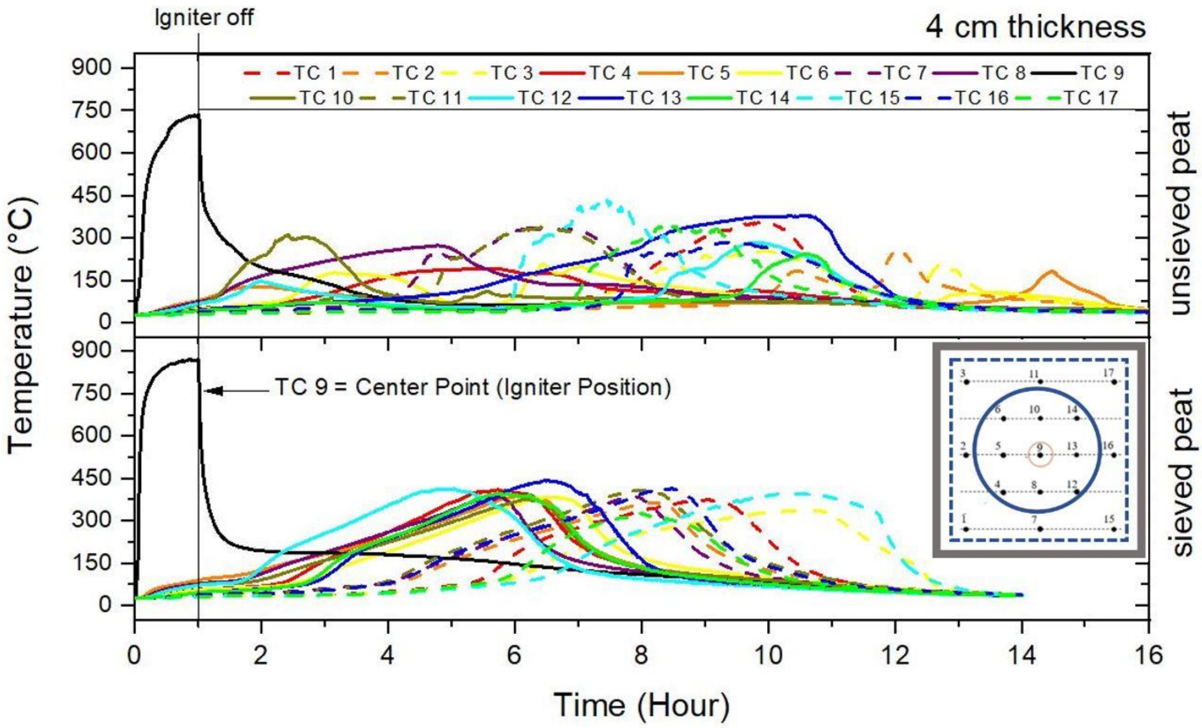


Figure 6- Temperature Measurements from Thermocouples from several Peat Layer Thickness PKY Peat

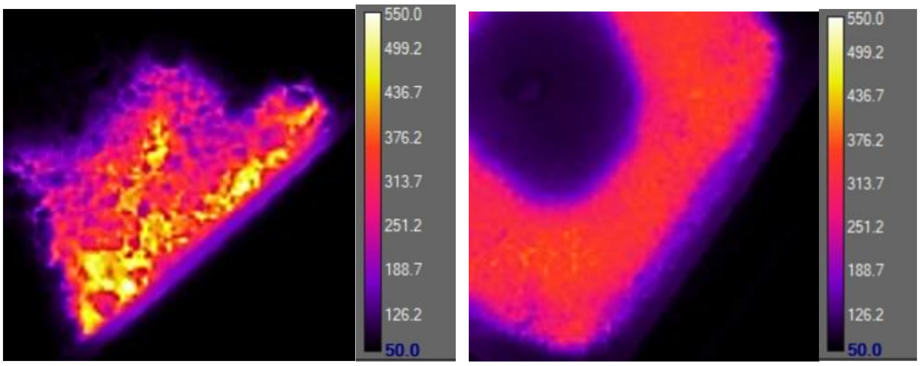


(a)



(b)

Figure 7- The difference in temperature readings between sieved and un-sieved on peat thickness (a) 3 cm, (b) 4 cm



(a) (b)

Figure 8- Differences in visualization results from surface textures captured by infrared cameras, (a) un-sieved peat samples, (b) sieved peat samples

Table 2- Bulk Density difference between sieved and un-sieved peat

Peat Sample	Preparation	Bulk Density (kg/m^3)
PKY	Un-sieved	278.79 ± 1.4
	Sieved	299 ± 4.4

3.3. Spread Analysis

The smouldering spread from PKY on each thickness can be seen in Figure 9. It can be seen that an increase in the speed of smouldering spreads with increasing thickness of the layer, but the increment is slowly decreasing when a certain thickness level. As the thickness of the peat layer decreases, it increases the surface to volume ratio (Rein 2009). Thus, in a negative energy balance, the heat generated by the combustion process cannot overcome the heat loss released to the environment. This causes the peat to burn to the extinction process. Smouldering combustion fails to survive on peat with layer thickness as thick as 2 cm where the spread of smouldering only lasts shortly after the heater is turned off. The heterogeneous nature of peat causes its smouldering speed to vary. The average smouldering spread rate for PKY includes 2.01 cm/h for 3 cm thick peat and 2.21 cm/h for 4 cm thick peat. In separate experiments, the horizontal smouldering spread rate was found to be about 2.82 cm/h using a 10 cm depth reactor and 2.91 cm/h using an 18 cm depth reactor (Putra *et al.* 2020).

$$v_r = \frac{s_{0\to n}}{\Delta t_{0\to n}} \qquad (2)$$

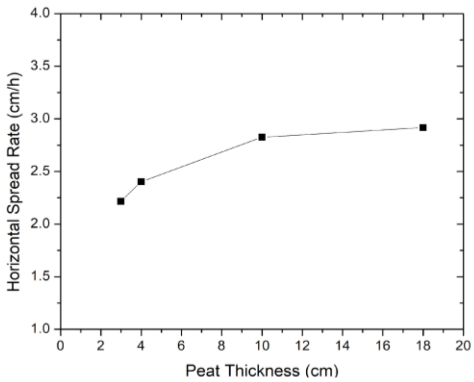


Figure 9- Horizontal spread rate of PKY Peat

4. Conclusion

Self-sustained smouldering depends on a positive energy balance between heat generation due to oxidation reaction and heat loss to the environment. The adjustable reactor used in this experiment was varied to represent 4 cm, 3 cm, and 2 cm peat layer thickness. The thickness and the bulk density of the peat layer play important roles on the horizontal spread probability, as it changes the heat balance between the heat generation at the reaction zone and heat loss to the environment. The smouldering spread rate increases by peat thickness from 2.01 cm/h to 2.21 cm/h and then reaches an asymptotic level. Extinction corresponds to a negative energy balance that was observed in 2 cm peat layer thickness in which a self-sustained smouldering front could not be maintained after the igniter was turned off.

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