Laboratory Scale Experimental Study of Foam Suppression on Smouldering Combustion of a Tropical Peat

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ABSTRACT

Solving peat fires problem continues to be a constant struggle in Indonesia as more hotspots are identified during the dry seasons. A number of research has been carried out to understand the most sufficient way to suppress peat fires using a range of different methods. This research was focused on the suppression of peat fire by using foaming-based suppression agent in the laboratory scale experiments. Experiments were carried out to explore the effect of foam suppression system on tropical peat fires. A solution of Class A Foam with a concentration of 3% was used to suppress Kalimantan peat fire with a density of ±0.3g/cm³. Sample used in the experiments was taken from Tumbang Nusa Village, Pulang Pisau District, Central Kalimantan Province, with a coordinate of S: -3⁰47’34”, E: 113⁰55’15”. This experiment will explore how many foam layers of certain heights are needed in order to extinguish peat fire. Peat sample was put in a 10x10x10 cm³ reactor, where a coil heater was turned on at 80 - 100W for 30 minutes to initiate a smouldering front. A set of type K thermocouples and infrared thermographs were used to explore the suppression mechanism that occurs. As the smouldering front moved away from the igniter to the other end of the reactor, foam with different thickness was poured on top of the peat to explore the effect of varying thickness on the suppression of peat fire. From the series of experiments, it was observed that there was a correlation between the thickness of the foam layer and the suppression of peat fires. The thickness of 10cm was found to be the most effective in terms of time at extinguishing peat fire. An average amount of 3.8L of foam per kilogram of Kalimantan peat was needed to extinguish peat fire. It was also found that the average amount of water needed to suppress peat fire using foam method was 3.4L/kg.

KEYWORDS:

smouldering, peat fire, fire suppression
INTRODUCTION

Wildland fires remain to be one of the most devastating environmental problems that occur across the globe. Not only it releases harmful substances into the air, such as carbon, but these chemicals also contribute highly to global warming. Peat is formed naturally as organic material goes through anaerobic decay in low pH conditions [1]. Indonesia is home to 20.6 million ha of peatlands. In 2016, the area of peatland in Indonesia was recorded to be as wide as 14.9 Million hectares which can be found across three main islands: Sumatera, Kalimantan and Papua [2].

Peat fire represents an example of smouldering fire that happens at low temperature, peaking at around 450 °C to 700 °C, and causes incomplete combustion [3]. This leads to a higher production rate of toxic gases and particulates compared to flaming combustion. Smouldering combustion is known to be flameless and moves slowly at a low and steady temperature [3]. The three main in situ methods to suppress peat fire have been identified by Hadden [4], which include cooling, smothering and burn-out. Water spray is an example of cooling method as it is able to bring down the temperature of burning fuels to below ignition temperature. However, the total amount of water needed to suppress peat fire can exceed 6 L/kg of peat [5]. Furthermore, this is caused by the change in peat characteristics when it is exposed to a very dry condition. Peat is known to have a hydrophilic characteristic which allows it to absorb water. However, in a very dry condition and the moisture content in peat lowers down to a certain point, peat is unable to absorb water and instead repels it [6]. With the lack of water in places where wildland fires occur, meeting the right amount of water needed to put out the fire may be problematic. On the other hand, Ohlemiller [7] finds that smothering method focuses on reducing the oxygen concentration below a critical level which ends the oxidation reactions.

Firefighting foam has long been a way of suppressing wildland fire. This research will explore the smothering mechanism to suppress peat fire using Class A Foam. Up until now there is still a lack of observation and research on how wildland fire, including peat fire, responds to foam application. There are many variables that may affect the performance of foam suppression system such as concentration of foam and the thickness of the foam layer. This research will observe the effect of the thickness of foam layer on the suppression of peat fires. Further research is being conducted to find out the effect of foam on peat fires suppression. Although the use of firefighting foam still sparks some controversy on the environmental impacts, it is still necessary to observe how smouldering peat reacts to foam.

EXPERIMENTAL METHODS

Peat Sample Preparation

The sample used in the experiment was taken from Tumbang Nusa Village, Pulang Pisau District, Central Kalimantan Province, with a coordinate of S: -3°47’34”, E: 113°55’15”. Peat sample was taken using a non-destructive method to provide a stable sample when it goes through testing. Peat sample from Kalimantan contains a lot of dead roots, twigs and branches as seen in Fig. 1(a) which shows that the sample used in the experiment is heterogeneous. Before testing, peat sample was dried using electric oven at 104°C for 24 hours. After drying, the moisture content of peat was checked using moisture balance. Peat sample used in the experiment had moisture content of less than 10%. The weight of the sample is maintained at ±300 grams, therefore the bulk density is approximately 0.3 gr/cm³.

![Fig. 1. (a) Dried peat sample, (b) Experimental Setup.](image-url)
Foam Suppression Experiment

A reactor, made from Stainless Steel, with a dimension of 10 x 10 x 10 cm was used in this experiment similar with the previous smouldering tests [4,5]. The reactor is also insulated to ensure that peat only comes in contact with oxygen at the top part. The sample was weighed beforehand to measure the mass loss after smouldering combustion occurs. To initiate smouldering front, coil heater was turned on at 100W for 30 minutes until combustion process was self-sustaining. Baseline experiment was carried out to observe smouldering combustion that occurs in the reactor and was left to self-extinguish. To examine the smouldering phenomenon, 9 type-K thermocouples are used at 3 different depths (25mm, 50mm, 75mm) at 3 distances (15mm, 50mm, 85mm from igniter) with a sampling frequency of 1Hz. The configuration of the experiment can be seen in Fig. 1(b). Apart from that, the mass of peat sample after smouldering combustion was recorded to obtain the mass loss during the test. Infrared camera, with an emissivity set at 95%, was also put in place to provide a qualitative visual representation of the smouldering combustion phenomenon. The photos were taken immediately after foam was poured onto smouldering peat from the side view.

After coil heater was turned off, peat sample was left to smoulder for 1 hour, which is the time required for the smouldering front to reach the other side of the reactor. At this point, suppression was carried out using Class A foam with a concentration of 1%. Foam is poured into an acrylic box, with varying height, was put on top the reactor to allow foam to spread evenly in top of the peat sample. The temperature at 9 different point at the reactor was observed to find out the effect of foam suppression method on the smouldering combustion of peat. The experiment was finished when all of the 9 thermocouples showed a temperature reading of below 80 °C.[5] The mass of the peat sample was measured after the experiment to find the mass loss.

The main objective of this research is to quantify the effectiveness of foam in suppressing peat fire. The independent variable in this experiment was the thickness of the foam which was represented by the height of acrylic boxes with the variation as seen in Table 1. This experiment will explore how many foam layers of certain heights are needed in order to extinguish peat fire.

Table 1. Summary of Experimental Variation.

| Thickness | 7.5cm | 10cm | 5cm | 2.5cm |

RESULTS AND DISCUSSION

Smouldering experiment was conducted beforehand to find out about the characteristics of smouldering combustion Kalimantan peat. As seen on Fig. 2(a), the first 30 minutes show a sharp increase in temperature due to the influence of the igniter. As the igniter was turned off, the temperature near the igniter plunges down to 400°C from 700°C. However, it slowly shows an increase measured by thermocouples at every depth and distance. Thermocouples at 25mm depth reach their maximum temperature at 466 °C in 3.18 hours. On the other hand, thermocouples at 50mm depth require a slightly longer time, 6.4 hours, to reach their maximum temperature at 480.31°C. Thermocouples at 75mm depth need the longest time, 8 hours, to reach their maximum temperature at 501.67 °C. This phenomenon shows that smouldering peat at the upper part of the reactor smoulders at a higher rate than peat at the lower part of the reactor. To explore this phenomenon, Fig.2(b) shows that the horizontal spread rate at the depth of 25mm is higher, 0.33 mm/min, than the average horizontal spread.
at the depth of 50mm, 0.17mm/min, and 75mm, 0.16mm/min. A similar trend can be found at the experiment using Papuan peat where the spread rate decreased from 0.57 to 0.2 mm/min with increasing depth.\[5\]

To observe the effect of foam on peat fires, a layer of foam was applied directly onto the peat with varying thickness. Fig. 3(a) shows temperature measurement from foam suppression experiment using 10cm thick of Class A foam. From the graph it is known that the thickness of 10cm was able to extinguish smouldering peat inside the reactor in 12 minutes. As the foam layer was applied on peat fire, all thermocouples show a sharp decline in temperature. Thermocouples located in 25mm depth and 50mm depth can be seen reaching a temperature of below 50 °C. On the other hand, thermocouples in 75mm depth show a more gradual decrease in temperature. This might have been caused by the foam still penetrating through the smouldering peat, therefore the time needed to extinguish the peat fire at the bottom of the reactor was slightly longer. Fig. 3(b) shows an infrared photograph of the experiment. As seen on the photograph, there was a distribution of temperature inside the foam layer which is shown by the gradient of colour with red indicating the hotter areas, and green showing a colder area. The lower part of the foam layer can be seen to be hotter than the upper part. This might be due to the heat released from the smouldering peat. As the foam layer also acted as a barrier to the atmosphere, the heat could not be released into the air causing an increase of temperature at the lower part of the foam layer. This may indicate that there was an increase in pressure inside the reactor as the foam was applied.

Fig. 3. Temperature measurement of foam suppression experiment using (a) 10cm thickness and (b) qualitative infrared photography

Fig. 4(a) shows a temperature measurement from the experiment using a 7.5cm thick layer of foam. From the experiment, it was found that a 7.5cm thick layer of foam was able to extinguish smouldering peat inside the reactor. The time required for the peat fire to be put out was 30 minutes. Unlike the experiment using 10cm thick layer of foam, the experiment using 7.5cm thick layer of foam shows a more gradual decrease in temperature at every depth as the foam layer was poured on the peat fire. The thermocouples at 15mm and
50mm distance from the igniter at all depths show a quicker decline in temperature. However, the thermocouples at 85mm distance from the igniter need longer time to reach the temperature of extinction. This might have been caused by the peat at 15mm and 50mm distance from the igniter have been burning for longer amount of time than peat at 85mm distance from the igniter. Therefore, the peat sample left at 15mm and 50mm is not as much as the peat sample at 85mm distance from the igniter, which causes the temperature to decline faster at 15mm and 50mm distance from the igniter. Fig.4(b) shows an infrared thermograph of the foam layer during the experiment. Similar to the phenomenon shown in Fig.3(b), the foam layer can be seen to have different temperatures at the upper and lower part, shown by the red and green colour. This shows that the lower part of the foam layer is hotter than the upper part which may be due to the heat released from the smouldering peat inside the reactor.

Fig. 5. Temperature measurement of foam suppression experiment using a thickness of (a) 5cm and (b) 2.5cm.

Experiments were also carried out using foam layer with a thickness of 5cm. As seen from Fig.5(a), 2 layers of foam with a thickness of 5cm were needed to extinguish peat fire. The first layer of foam managed to bring down the temperature of smouldering peat up to 500 °C, which can be seen by the thermocouple at 15mm and 50mm from igniter and 25mm depth. After the first layer was applied, thermocouple at 15mm from igniter at the depth of 50mm, indicated an increase in temperature or re-ignition phenomenon. The second foam layer was applied after the first foam layer has completely disappeared. The second foam layer was able to extinguish the smouldering peat by bringing down the temperature to below 80 °C. The time required for the peat fire to be put out completely using 5cm thick foam layer was 47 minutes, which was longer than the time needed to extinguish peat fire using 10cm thick foam layer or 7.5cm thick foam layer.

Experiments were also conducted using foam layer with a thickness of 2.5cm. As seen from Fig.5(b), 3 layers of foam with a thickness of 2.5cm were needed to fully suppress smouldering peat inside the reactor. The first layer of foam did not last long, as it only took approximately 10 minutes for the foam layer to disappear. During that time, the thermocouples at all depths record a sharp decline in temperature. However, it was not enough to fully suppress the fire. The second layer of foam with the same thickness was applied immediately after the first layer disappears. The second layer of foam managed to stay for longer and bring the temperatures down to near 100 °C at 50mm depth and 75mm depth. However, as the second layer of foam disappeared, there was an indication of re-ignition as seen on Fig.5(a). The third layer of foam was applied and it managed to put out the peat fire. The time required for the burning peat to be completely suppressed was 71 minutes which was the longest time out of all the experiments.

Fig.6 shows the residual mass fraction of each experiment. As seen from the graph, the highest mass loss, 74.05%, can be observed during the baseline experiment which used 0cm thick of foam layer. As foam was applied on peat to explore how peat fire reacts to foam application, it can be seen that the total mass loss in the experiment where peat fire was suppressed (10cm, 7.5cm, 5cm, and 2.5cm) are significantly lower than that of the baseline experiment. The lowest mass loss can be seen at the experiment using 2.5cm thick of foam layer which is 31.4%. However, the difference in percentage of mass loss is not significant.
CONCLUSION

Through the series of experiments, it can be found that there was a correlation between the thickness of foam layer on the suppression of peat fire. The thickness of 10cm was found to be the most effective in terms of time at extinguishing peat fire. An average amount of 3.8L of foam per kilogram of Kalimantan peat was needed to extinguish peat fire. It was also found that the average amount of water needed to suppress peat fire using foam method was 3.4L/kg. Foam layer acts as a barrier between smouldering peat and the air, therefore with the presence of foam layer, the combustion process inside the reactor is disturbed as there is no oxygen supply. Apart from that, Class A Foam also has the ability to wet the peat sample, causing a decrease in temperature. On the other hand, further studies on the interaction between foam and peat surface still need to be carried out to provide a better understanding of the suppression mechanism using foam.

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