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Experimental study of the effect of water spray on the spread of smoldering in Indonesian peat fires

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ABSTRACT

Peatland fires remain a major contributor of environmental problems in Indonesia. Several studies on peat fire suppression have been conducted with multiple methods, such as quarrying, water spray, artificial rain, and foam spray. This research is focused on laboratory scaled experiments of Indonesian peat smoldering fire behaviour and suppression by a water mist system. The peat used in this work was obtained from two different locations, namely Papua and South Sumatra, Indonesia. During the suppression tests, the intensity of the water mist spray was varied by changing the distance between the nozzle and the peat surface. Meanwhile, the time periods of spray were 15 min (short period of suppression) and approximately 2 h for full suppression until the peat fire was extinguished. The peat temperature and the total mass lost during the smoldering reaction were recorded to get the burning rate ratio for each sample. The spread rate of the smoldering process was identified by the changes in the local temperatures of the peat bed. The results show that the spread rate of the smoldering combustion front was affected by particle size and permeability of peat material. The short duration of water suppression failed to extinguish the peat fires. A re-ignition phenomenon was identified due to the persistence of stored heat in the core of the peat. In addition, the total water required to fully suppress both peat fires is about 6 L/kg peat.

1. Introduction

Forest fires in Indonesia remain a major environmental problem. The Indonesian archipelago has a lot of scattered hotspots, caused by wild land and peat fires. For example, on December 15, 2015, NASA Fire Information for Resource Management identified around 96,937 hotspots on Sumatra Island [1]. One of the main contributors of forest fires in Indonesia is peatland fire. Indonesia, with 188.2 million ha area, is comprised of both dry lands and swamps. The swamp area itself, which is 33 million ha, consists of 20.6 million ha of peatlands or around 10.8%. Most of the peatlands are located in three major islands, which are Sumatra (35%), Kalimantan (32%), and Papua (30%). The remaining 3% are located in Sulawesi and spread across confined areas [2,3].

Peat fire is an example of smoldering fire which occurs at low-temperature and generates incomplete combustion. Smoldering combustion produces toxic gases and particulates at a higher rate than flaming combustion. Several trials for fire suppression on peatlands have been conducted using methods such as quarrying, water spray, foam spray, and artificial rain. Much like fire suppression in coal, Colaizzi [4] showed that the extinction process is costly, and often fails to produce the desired result.

According to Hadden [5], there are three main in situ mechanisms for fire suppression in smoldering fire: through cooling, smothering, and burn-out. The first two mechanisms are based on the physical and chemical processes which play a role in smoldering combustion. For cooling, the temperature of peat is reduced to below the critical re-ignition temperature by adding a suppression agent below the surface. Suppression agents can be in the form of gas or liquid [5]. The smothering mechanism has been identified by Ohlemiller [6] and shows that when oxygen concentration is reduced to below a critical value, oxidation reactions will stop. However, higher concentration of oxygen in the atmosphere would increase the smoldering spread rate, and the critical oxygen concentration is influenced by several parameters, such as the moisture and inorganic content within the peat bed [7,8]. The air that is used as the oxidizer produces a buoyancy effect on the burned fuel during the smoldering process [9]. In this research, a water mist suppression system is used to see the effect of suppression by forced cooling for peatland. There are many variables that could affect the performance of the water mist system. Xiaohui et al. [10]

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studied the performance of water mist in an enclosed space by using nozzles with different characteristics. He found that increasing the spray cone angle and decreasing the flow rate would increase the extinguishing time [10]. Pressure, droplet size, and density of discharged water determine the water mist system performance.

1.1. Smoldering peat fire and its control

Peat fires, which means smoldering fires, tend to move slowly, have a low and stable temperature, and are flameless [6]. Smoldering is a combustion process that includes heterogeneous chemical reactions, and also heat, mass, and momentum transfer [11]. Ohlemiller [6] and Rein et al. [12] explained in general that smoldering has four stages while it is spreading, resulting in the structure of a smoldering front. The smoldering front therefore consists of four zones: the preheat zone, the evaporation zone, the burning zone, and the char and ash zone [6]. These are the explanations of smoldering front:

1. Preheating of Virgin Fuel Zone
   The zone where the virgin fuel is preheated is an area where the initial temperature is increasing, from the initial fuel temperature until the evaporation point, thus the temperature of the virgin fuel will increase without the creation of gas.
2. Evaporation Zone
   The evaporation zone is an area where the endothermic process happens within the temperature range of 80–100 °C and produces water vapor.
3. Burning Zone
   Burning zone is an area where the oxidation and pyrolysis processes occur and release the net heat.
4. Char and Ash Zone

The char and ash zone is an area where the smoldering process stops and creates char along with ash. Ash is made from remnants of mineral fuels, while char is made from incomplete combustion.

Tropical peatlands have an important role in the ecosystem when considering both local and global perspectives [13]. Thus, minimizing the negative environmental and socioeconomic consequences of peat fires becomes necessary. An integrated strategy for preventing the occurrence of peat fire as well as measures to control the fire when hotspot are identified should be integrated into local development strategies in the areas where natural peatlands are located [14]. Because the fire risk increases if the water table falls below 0.40 m [15], maintaining the water table above the critical value by canal blocking strategies is a potential option for hydrological restoration of degraded tropical peatlands [13]. Nevertheless, once the peat fires occur in the degraded peatlands, measures of suppressing the fire should be conducted effectively. These measures include direct attack by sending fire brigades equipped with portable pumps, hoses, and spraying nozzles, or even aerial water bombing using helicopter or aircraft. However, for those methods, the amount of water required for peat fire extinction and cooling currently has not been well established.

The objective of this research is to study the effect of water mist spray intensity on the suppression of smoldering combustion of Indonesian peat. Samples of peat from South Sumatra and Papua were tested and compared, and experimental studies on the smoldering combustion behaviour of Indonesian peat were conducted. It is expected that a minimum amount of water spray is required for effective suppression of smoldering in peat fires.

2. Experimental methods

2.1. Peat sample preparation

Two sample types of peat for this research were taken in different locations as shown in Fig. 1. The first sample was taken in Kabupaten Ogan Komering Ilir (OKI), South Sumatra Province, Indonesia, with coordinates S: 03°24′00.7″; E: 104°52′39.1″. The second sample was taken in Kabupaten Sarmi, Papua Province, with coordinates S: 01°55′14.11″; E: 138°6′17.35″. Both samples were taken at a depth of 60–120 cm with undisturbed sampling methods in order to obtain samples with stable conditions until the time of the test. The difference between these two types of peat can be seen from the particles themselves, as Papuan peat tends to be finer than South Sumatran peat which mainly consists of dead roots and decomposed remnants of trees as seen in Fig. 2(a). This difference in consistency affects the physical and thermal properties of the peat.

The peat samples were dried using an electric oven at a constant temperature of 100 °C for 24 h. The moisture content of the dried peat was measured by moisture balance. The porosity values of the peat have been observed using a scanning electron microscope. Fig. 2(b) shows that the porosity for Papuan peat is approximately 17.7 μm, and 33 μm for South Sumatran peat. These porosity values could affect the smoldering reaction and the suppression process.

Proximate and ultimate analysis from peat samples were conducted by the Research and Development Center of Mineral Technology Indonesia and can be seen in Tables 1 and 2. Parameters obtained from the proximate and ultimate analysis show characteristics that will implicitly affect the combustion process such as volatile matter, fixed carbon, ash, bed density, and calorific value. Parameters such as volatile matter, higher percentage of oxygen concentration, and lower bed density will result in faster flame propagation rates. Nonetheless, the combustion process of Papuan peat will produce heat energy that is higher than South Sumatran peat.

2.2. Smoldering experiment

Baseline smoldering experiments of the peat were conducted by using combustion test equipment based on the work and experimental apparatus of Hadden [5] and Rein et al. [16]. The experimental apparatus was a stainless-steel container of 100×100×100 mm^3, isolated by a calcium-silicate board insulation, shown in Fig. 3(a) and (b). A coil heater ignitor was placed on the left side for a length of 90 mm in order to produce uniform combustion. In the beginning, 80–100 W of power is supplied to the electrical coil heater for 120 min to help the initial combustion process and to prevent early fire extinguishment.

In order to measure the temperature, K-type thermocouples are placed in nine different locations: three thermocouples placed in each depth of 25 mm, 50 mm, and 75 mm at distances 15, 50, 85 mm from the igniter. The thermocouples used have a diameter of 15 mm, a 500 mm long probe, and have a measurement accuracy of ± 2 °C. The container has 6 mm diameter holes (representing 1.8% opening area from total experiment apparatus) in order to provide airflow to help maintain the burning process [5]. Empty spaces are filled by samples of peat as seen in Fig. 3(b).

2.3. Water mist suppression experiment

There are two approaches that are utilised in this study: variation in watering altitude with a limited amount of water, and also the amount of water needed to extinguish the fire. Fig. 4 illustrates the full-scale water mist experiment with spraying height variations of 10 and 50 cm. This experiment was conducted to obtain the spraying intensity ratio relative to the ratio of burned peat as in Table 3. Once the combustion process was self-sustaining, the water mist system was activated for 30 min after the igniter was turned off, and was run for 15 min with a flow rate of 0.2 L/min directly onto the burning peat. The experiment to determine the amount of water needed for fire suppression was conducted with a constant spraying height of 10 cm. Before the water reached the nozzle, it passed through a pressure vessel and pressure gauge, to ensure the pressure output at the water mist nozzle was as expected.