Performance improvement of palm oil foaming agent concentrates as fire extinguishment materials in peatlands

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Abstract. Foaming agent concentrate made from palm oil produced as a fire extinguishing material in peatlands at a laboratory-scale test were able to extinguish a fire within 3.16 to 4.49 hours. Fire extinguishing ability of this foaming agent concentrate resulted in a lower solution use and shorter extinguishing time than water. However, when compared to commercial products, fire extinguishing time was still longer although the amount of solution needed to extinguish the fire was lower. Therefore, it was necessary to improve the formula to produce a foaming agent concentrate that was able to extinguish the fire in a shorter time with a lower amount of fire extinguishing solution. This study aims to improve the performance of palm oil foaming agent concentrate on extinguishing the fire in peatlands. Efforts to improve the performance were made by reformulation and the addition of chemical fire retardants. Results showed that the addition of fire retardant reduced foaming ability, increased surface tension, lowered viscosity, lowered contact angle, and reduced fire extinguishing time to about 13.08-69.21%.

Keywords: Improved formulation, palm oil foaming agent concentrate, fire extinguisher, reduction of extinguishing time

1. Introduction

In fire extinguisher application, foam is used to cool the fire and avoid recontact with oxygen that may lit the fire back. The foaming agent used in peatlands should be environmentally friendly, biodegradable, and nontoxic to biota and the environment. Studies have been done on the utilization of vegetable oil derivatives as firefighting agents that are environmentally friendly. Mizuki et al. [1] formulated a firefighting agent by using long-chain fatty acid (LCFA), biodegradable chelating agent, and additive to produce a firefighting agent which was also biodegradable. The concentration of the firefighting agents was 1% to produce an environmentally friendly firefighting agent. However, the resulted foam had a shorter life than the synthetic firefighting agent. Kawahara et al. [2] formulated a firefighting agent by using a biodegradable chelating agent (MGDA) which was different from that used by Mizuki et al. [1] who produced a firefighting agent which was also biodegradable. Rivai et al. [3] developed a foaming agent concentrate by using potassium palmitate, sodium laurate, and potassium methyl ester synthesized from palm oil. The product was as a fire extinguisher material to be applied in peatlands. The utilization of potassium palmitate as the main ingredient in the formula was decided based on the notion that this material has high foam stability [4] which is even higher than that of sodium laurate [5]. The resulted foaming agent concentrate had an ability to reduce surface tension, reduce interfacial tension, form foam, and improve the effectiveness of water used in fire extinguishment. Results of an extinguishment test conducted based on the methods of Rein et al. [6] and Ramadhan et al. [7] showed that this foaming agent concentrate had an ability to extinguish
the fire for 3.06-4.94 hours with the use of 3% solution by about 42.4-105.91 g. Meanwhile, fire extinguishment by only using water took 5.53 hours and a total of the water volume of 128.49 g. In order to make fire extinguishment faster and a minimal amount of solution needed, efforts to improve the performance of foaming agent concentrate needs to be made. In peatlands, this effort can be made by reformulating the concentrate by adding in chemical substances functioning as fire-retardant. A chemical substance that has a fire extinguishment property will increase the performance of water in fire extinguishment [8]. Some chemical substances commonly used as fire-retardant include ammonium phosphate, chloride, ammonium sulfate, phosphoric acid [9], MgCO$_3$ [10], combination of MgCO$_3$ and 2ZnCO$_3$.3ZnO.4H$_2$O (AZC) [11], Mg(OH)$_2$, Al(OH)$_3$ [12, 13], and CaCl$_2$ [14]. This study aimed to improve the performance of palm oil foaming agent concentrate in extinguishing fires in peatlands through the addition of chemicals that have a fire retardant property.

2. Materials and Methods

The materials used in this study include palmitic acid, lauric acid, methyl ester, NaOH, KOH, EDTA, solvents (hexylene glycol, propylene glycol), emulsifier, water, MgSO$_4$, MgCO$_3$, and CaCl$_2$. Formulation stages consisted of (a) formulation of foaming agent concentrate through the addition of fire retardant at various concentration of 0.1-0.2% and test it for its physicochemical properties and (b) fire extinguishing test by using peat soil sample. Foaming agent concentrate was made based on the modified formula by Rivai et al. [3]. Several tests on some parameters including foam stability, foaming ability, surface tension, interfacial tension, viscosity, and contact angle, and a fire extinguishing test at a laboratory scale were also conducted. All tests were conducted with two replicates. Foam stability and foaming ability were measured at 1% concentration while interfacial tension, surface tension, and viscosity were measured at 100 concentration. The contact angle was measured at 3% concentration which was similar to the concentration of the solution used in the fire extinguishing test using peat soil sample. As a control, similar parameter tests were conducted on commercial products. The fire extinguishing test at a laboratory scale was done by using a stainless steel reactor sized 100 x 100 x 100 mm. The installation of a peat burning test at a laboratory scale is depicted in Figure 1. The reactor was equipped with an electric heater of 100-300 Watt as a firing trigger [6]. Three thermocouples were put onto the reactor in a 25 mm row spacing. The thermocouples were connected to a datalogger and a computer to record temperature changes as an indicator of the burning process occurring within the reactor [7]. The tests were conducted by following several steps including (a) setting up the installation of performance test, (b) burning process with trigger fire temperature of 350-650 °C for 3-5 minutes, (c) fire extinguishing after 4-hour burning by using liquid foam obtained by mixing foaming agent solution (3%) with water, and (d) controlling temperature to measure burning and extinguishing performance. Results of the fire extinguishing performance test of foaming agent concentrate before and after the addition of fire retardant were compared to those of commercial products.
3. Results and Discussion

3.a. Formulation of foaming agent concentrates through the addition of fire retardant and test of its physicochemical properties

Foaming agent concentrates modified in this study were 23, 45, and 46 formulas whose physicochemical properties had been already known. The concentration variations in the formulas include potassium palmitic acid 3.48-4.44%, sodium lauric acid 2.61-7.41%, potassium palm methyl ester 2.61-7.41%, with other additional and additive materials consisting of diluents 5.52-6.96%, emulsifier 4.35-7.41%, chelating agent 0.69-1.74%, and water 66.67-69.57%. Three chemical substances functioning as retardants including (A) MgSO$_4$, (B) MgCO$_3$, and (C) CaCl$_2$ at various concentrations of 0.1-0.2% were added into each formula. This low concentration of fire retardant was applied in order to produce a solution that was not too thick and still in a liquid form. Foam concentrate of class A had physicochemical properties which could be used as standards for concentrate production. These properties include viscosity 35.57 cP at 25 °C, specific gravity 1.0240 at 15.6 °C, surface tension 26.51 dyne/cm (concentrate) and 30.69 dyne/cm (0.3% concentrate), and density 1.025 g/ml at 20 °C [15]. Therefore, the viscosity value of the solution was made as a limit and only samples having viscosity values less than 50 cP were used for further analysis. A solution that is too thick causes difficulty in the foaming process. The appearance of some of the products is depicted in Figure 2.

![Products of foaming agent concentrate](image)

Figure 2. Products of foaming agent concentrate

The different concentrations of the ingredients of the formula made the physicochemical properties of each formula also different. Physicochemical properties including foam stability, foaming ability, surface tension, interfacial tension, and viscosity of foaming agent concentrate were measured before and after fire retardant was added in. The results of the physicochemical properties of the foaming agent concentrate produced shown in Table 1. Foam stability values were measured as the difference between foam height at minute 0 and that on day 3 after homogenizing. The values were expressed in cm and converted into percentages. Results showed that foam stability values before the addition of fire retardant done on day 3 were 79-92% which changed to about 74-95% following the addition of fire retardant. Foaming ability was referred to as the ability of a liquid to form a foam at minute 0 after homogenizing which was compared to that of water and expressed in percentage. Foaming ability of foaming agent concentrate before the addition of fire retardant was 295-344% and this changed to about 231-320% following the addition of fire retardant. Interfacial tension values of foaming agent concentrate before fire retardant was added were 0.24-0.31 dyne/cm. These values changed to about 0.21-0.3 dyne/cm after the fire retardant was added in.
Table 1. The results of the physicochemical properties of the foaming agent concentrate produced

| No. | Parameter                               | Concentrate Foaming Agent Produced | Commercial Product |
|-----|----------------------------------------|------------------------------------|-------------------|
|     |                                        | Before the addition of fire retardant | After the addition of fire retardant |         |
| 1   | Foam stability (%, day-3)               | 79 – 92                           | 74 – 95           | 0       |
| 2   | Foam ability (%)                       | 295 – 344                         | 231 – 320         | 195     |
| 3   | Surface tension (100%, dyne/cm)        | 25.21 – 32.58                     | 27.12 – 32.73     | 24.34   |
| 4   | Interfacial tension (100%, dyne/cm)    | 0.24 – 0.31                       | 0.16 – 0.3        | 0.16    |
| 5   | Viscosity (100%, cP)                   | 16.3 – 44.9                       | 8.03 – 51.38      | 7.3     |
| 6   | Contact angle (3%, °)                  |                                   |                   |         |
|     | a. Min-0                               | 43.5 – 49                         | 27.46 – 46.70     | 20.7    |
|     | b. Min-15                              | 7.1 – 15.5                        | 4.85 – 14.45      | 0       |
|     | c. Min-30                              | 0 – 9.4                           | 0 – 3.74          | 0       |

Measurement of surface tension values is a good approach to obtain appropriate and stable formulation products [16, 17]. Surface tension values of foaming agent concentrate were found to be 25.21-32.58 dyne/cm before the addition of fire retardant and about 27.12-32.73 dyne/cm after the addition. Some of these surface tension values have met the requirement [15] but some were a little higher. According to Wu and Liao [8], the viscosity parameter is one of the factors to be considered in the development of fire extinguishment materials. This is important as there is an increase in shear rate and a decrease in viscosity level which leads to a low resistance when the extinguishment material is still in the pipe and pump of a spraying tool. After the extinguishment material is sprayed over a surface, the shear rate decreases while viscosity and adhesion increase. In this study, the viscosity values of foaming agent concentrate solution before the addition of fire retardant were 16.3-44.9 cP and these values changed into 8.03-51.38 cP following the addition of fire retardant.

High contact angle values result in low wettability [18]. Contact angle values were measured at minute 0, 15, and 30. Results showed that before the addition of fire retardant, contact angle values of foaming agent concentrate solution were 43.5-49° in minute 0, 7.1-15.5° in minute 15, and 0-9.4° in minute 30. After the addition of fire retardant, these values became 27.46-46.7° in minute 0, 4.85-14.45° in 15, and 0-3.74° in minute 30. Responses to the addition of fire retardants were similar in all formulas and tended to be a decrease in contact angle values which occurred from minute 0 to 30 by 80-88%. This lower contact angles indicated that the resulted foaming agent concentrate had high wettability. Compared to that of water which reached 65.2° [19], the contact angle of foaming agent concentrate in this study was lower at 1% concentration. This indicated that the resulted foaming agent concentrate had higher wettability than water did. When they were applied as fire extinguishment materials, these foaming agent products would have a higher penetration ability than water.
3.b. Fire extinguishing test

In general, peat burning is characterized by the existence of smoldering which has no flame. Different from common on-surface vegetation burning, peat burning occurs slowly and takes a longer time. An illustration of peat burning is depicted in Figure 3. The results of other studies showed that peat fire spreading rates were about 2.08-6.25 [20] and 0.61-3.05 cm²/hour [7]. Fire spreads continuously in a horizontal direction until fire extinguishing is done or burned material is used up. Vertically, fire spreads continuously in a downward direction and the resulted heat makes the wet peat dry and ready to get burned. This makes peat burning keep occurring until the heat can no longer dry the existing wet peat. In addition, this downward burning can be terminated when there is an inadequate supply of oxygen as a result of peat pore blockage or when there is fire extinguishing material flowing down to the peat layer.

Figure 3. Illustrated peat burning at a laboratory scale

In order to assess fire extinguishing performance, datalogger connected to a computer was used to obtain burning temperature and fire extinguishing performances. Temperature movement which was processed in the form of thermal graphs was used as an indicator of the working process in the burning reactor. After fire extinguishing was done and thermal graphs showed a decreasing temperature trend from above 400 °C to below 50 °C, it should be confirmed that no longer burning process occurred in the reactor and for this purpose, an infrared camera was used. A thermal contour after peat burning extinguishment was done as depicted in Figure 4 that showed the peat temperature was already below 50 °C indicating that there was no longer any burning activity in the reactor which could recreate the flame. In this test, horizontal fire spread was found to occur at 3.6 cm²/hour at room temperature and pressure and under the condition that the peat was clean from organic litter and evenly dried with a water content of 12-15%. This fire spread represented the movement of fire from the central point where burning was initiated to the horizontal axis.

Figure 4. Thermal contour prior to peat burning extinguishment
Two key parameters for fire extinguishment applications are foam stability and foaming ability [21]. Therefore, along with the contact angle, these parameters were used to select samples to be used in the fire extinguishing test. There were 6 selected samples with higher foam stability and foaming ability and lower contact angle values than the other samples. These selected samples included formula 23 with magnesium sulfate 0.2% addition (23A2), formula 23 with MgCO$_3$ 0.1% addition (23B1), formula 23 with CaCl$_2$ 0.1% addition (23C1), formula 45 with CaCl$_2$ 0.1% addition (45C1), formula 46 with MgSO$_4$ 0.2% addition (46A2), and formula 46 with CaCl$_2$ 0.2% addition (46C2). Fire extinguishing results with and without fire retardant addition were compared. It was shown that fire retardant addition in formula 23, 45 and 46 resulted in a significant decrease in extinguishing time from 3.16-4.49 hours to 1.38-2.75 hours. This meant that there was a reduction of extinguishing time by about 13.08-69.21%. However, except for formula 45C2, in all other formulas, there was an increased solution use by about 19.14-75.06%. Formula 46A2 and 23A2 were found as the best formulas which could extinguish the fire within the shortest time similar to that of commercial products with lower solution volume. This showed that formula 23 and 46 which had an addition of MgSO$_4$ by 0.2% had a fire extinguishment performance equal to that of commercial products which usually required only low solution volume to extinguish the fire. The volumes of solution and fire extinguishment time required by foaming agent products before and after fire-retardant addition and by commercial products (AFFF) are depicted in Figure 5.

![Image of Figure 5](image_url)

**Figure 5.** The volume of the solution and fire extinguishment time required by foaming agent products before and after fire-retardant addition and the commercial products

### 4. Conclusions

In general, the addition of fire retardant reduced foaming ability, increased surface tension, lowered viscosity, lowered contact angle, and reduced fire extinguishing time by about 13.08-69.21%. Formula 23 and 46 with 0.2% addition of MgSO$_4$ had fire extinguishment performance equal to that of commercial products with low requirement for solution volume.

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