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Formulation and performance test of palm-based foaming agent concentrate for fire extinguisher application

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Formulation and performance test of palm-based foaming agent concentrate for fire extinguisher application

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Abstract. The utilization of foaming agent for fire extinguisher application improves the efficiency of water as a fire extinguishing agent, lowers surface tension, and acts as a foaming agent. The formed foam cools the fire down and covers the burned material to avoid it from further contact with oxygen which may reignite the fire. This study aimed to produce and assess the performance of foaming agent concentrate from palm oil as a fire extinguisher agent. In the performance test, measurements were taken on foam stability, foaming ability, surface tension, interfacial tension, viscosity, contact angle, density, and specific gravity. The formulation was conducted by using the best produced potassium palmitate, potassium methyl ester, and sodium lauric combined with diluents, chelating agent, and other additives at various composition comparisons. The produced foaming agent concentrate was found to be in a rather paste and liquid form with viscosity of 2.34 – 253 cP. It was also found that the resulted foaming agent concentrate dissolved in water at the concentration rate of 1% had a foam stability level of 30-91%, foaming ability of 288 – 503%, surface tension of 19.68 – 25.05 dyne/cm, interfacial tension of 0.54 – 4,20 dyne/cm, viscosity of 1.00 – 1.05 cP, contact angles of 53.75 – 63.79^o at 0 minute and 11.84 – 22.42 ^{o} at minute 10, density of 0.99586 – 0.99612 g/cm^3, and a specific gravity of 1.00021 – 1.00046. Based on foam stability, foaming ability, and surface tension parameters, it was concluded that NF5 and NF17 were the best formulas.Compared to the other formulas, NF5 formula had the best droplet diameter (minimum 0.14 mm) and droplet density (maximum 3056 droplets/cm^2).

Keywords: palm oil, potassium palmitate, potassium methyl ester, sodium lauric, foaming agent concentrate, fire extinguisher

1. Introduction

Fire-fighting agent or fire-fightingfoam consists of surfactant as the main component which increases the efficiency of water utilization, reduces surface tension of a liquid, and improves the stability of foam formation. Imported surfactant which is relatively more expensive has long been used for fire extinguishment. Therefore, it is important to seek for an alternative surfactant from potential agricultural products such as oil palm in Indonesia in order to cut off the country's high dependency on imported surfactant. Palm oil-based surfactant is environmentally friendly as it is highly degradable. In addition, it has low toxicity level and sustainable availability as palm oil feedstock in Indonesia is plenty. It is expected that the utilization of palm oil as a foaming agent increase the value added of palm oil, diversification of palm oil processed products, and reduce dependency on imported surfactant.

Foam is defined as a dispersion system consisting of gas bubbles covered by liquid film. Significant differences in density levels of bubbles and liquid medium make the system separate quickly to form two layers with the bubbles being the top layer. When gas bubbles are formed under the liquid surface, the bubbles will immediately break up as a result of drainage created by a gravitational or downward force. Therefore, pure liquid will have no bubbles unless a surfactant is added in as surfactant reduces gas/liquid interfacial tension allowing the dispersion of gas in liquid to occur so that foam is formed [1, 2].

Fire is an event in which flame in uncontrollable. In the Regulation of Manpower and Transmigration Ministry Number 04/MEN/1980 Chapter I Article 2, Paragraph 2, there 4 categories of fires, namely A, B, C, and D. Meanwhile, National Fire Protection Association (NFPA) classifies fires into 5 categories including A, B, C, D, and K. Some countries have even determined an extra fire class (E). Each type of fires can be handled with different type of foam. In Indonesia, A fire class is the most common fire type found. This fire types occurs on solid materials wood, paper, fabric, plastic and other materials except steel. This fire can be handled effectively by using sand, soil/mud, extinguisher powder, foam, and water. The suitable foam to handle this type of fire is class A foam.

Class A foam consisted of a mixture of water, foam concentrate, and water. This foam has different characteristics according to the production method used, concentration of foam solution, type of concentrate used, length of hose, type of nozzle, and aeration. The concentration of class A foam used for class A fire is considerably low, namely 0.1 to 1% (U.S. Department of Homeland Security 1996). Class A foam concentrate has physicochemical properties which can be used as the standard of concentrate production. These include 35.57 cP viscosity at 25°C, 1.0240 specific gravity at 15.6^{o}C, 26.51 dyne/cm (concentrate) and 30.69 dyne/cm (0.3% of concentrate) surface tension, and 1.025 g/ml density at 20^{o}C [3]. The use of 0.3% concentration is selected based on results of several studies which showed that in class A foam solution, higher concentration did not result in any changes in surface tension.

Class A foam has several advantages. Compared to water, it extinguishes fire more rapidly providing more efficient use and conservation of water. Hose containing this foam is lighter than that containing water making fire fighters easier to maneuver in using it. Class A foam forms a blanket covering the surface of fuel so that it can lower the temperature of the burnt materials, avoiding contact between fuel and oxygen, cover wider surface, and lasts longer making it suitable for fighting fire in areas with limited water supply. This type of foam can reduce surface tension allowing water to go deeper into the center of the flame in the burnt materials.

Studies have been conducted to assess the utilization of plant oil derivatives as environmentally friendly firefighting agents. A firefighting agent was made from sodium oleic (10% w/w), potassium lauric (6.87% w/w), potassium palmitic (0.1% w/w), GLDA (40% w/w), and diluents (43.03% w/w) {4]. Ethyl estersas the result of palm oil trans esterification also were used as material for a firefighting agent [5]. Abiodegradable firefighting agent was made by using potassium lauric and potassium oleic at the ratio of 4:6, and potassium lauric and sodium oleic at the ratio of 4:6, and a *biodegradable chelating agent*(MGDA), with an expansion ratio of 9.6 times that of commercial firefighting foam for structural fire [6].

Based on the above considerations, this study was aimed at producing a foaming concentrate from palm oil and assessing the performance of it as firefighting agent. The foaming agent concentrate was developed for class A fire.

2. Materials and Methods

The main materials used in this study included potassium palmitic, potassium methyl ester, sodium ethyl ester, sodium lauric, sodium oleic, sodium methyl ester, diluents (propylene glycol, hexylene glycol), EDTA chelating agent, emulsifier, and water. Homogenizerwas used to make the formula mixed. Foaming stability and ability of solution were measured by diluting 1% sample in 99% distilled water. The dilution was stirred for 15 minutes by using a homogenizer before it was transferred into 100 ml capped graduated cylinders, shaken up 20 times in constant speed. The volume of foam was recorded on day 0, 1, 2, and 3. AnAnton Paar DMA 4500M densitometer was used to measure the density and specific gravity of foaming agent concentrate formula. A Brookfield DV-III Ultra viscometer was used to measure the viscosity of foaming agent concentrate and foaming agent concentrate solution. Contact angle of foaming agent concentrate solution was measured by using a Phoenix 300 contact angle analyzer. Interfacial tension of foaming agent concentrate solution was measured by using a TX500C spinning drop tensiometer. TASCO MD-150 mist blower was used to measure droplet diameter and density. Droplet size was measured by using Sharp Develop application. The pixel unit produced from this application was converted to micrometer unit. Fire extinguishment performance of foaming agent concentrate formula was assessed by using a portable foam educator. The foaming agent concentrate test was conducted at 1% concentration.

2.1. Formulation of Foaming AgentConcentrate

The resulted foaming agent concentrate formulation was modified from [4] and [6], by using combinations of six types of foaming agent products including potassium palmitic acid, sodium palm ethyl ester, sodium lauric acid, sodium oleic acid,sodium palm ethyl ester and potassium palm methyl ester produced by [7]. The concentration variations included potassium palmitic acid 2-3%, sodium palm ethyl ester 0-4%, sodium lauric acid 2.5-5%, sodium oleic acid 0-3%, sodium palm methyl ester 0-2,5%, and potassium palm methyl ester 0-2.5%, with other additional and additive materials consisting of diluents 2-6%, emulsifier 0-15%, chelating agent 1-2%, and water 71-80%. The mixing process was done at room temperature by using a homogenizer with a stirring speed of 2000 rpm for an hour. Analyzes were done on foam stability, foaming ability, surface tension, interfacial tension, viscosity, contact angle, density, and specific gravity.

2.2. Performance Test of Foaming Agent Concentrate for Fire Extinguishment

The performance of foaming agent concentrate for fire extinguishmentwas tested by measuring foaming effectiveness and using the foaming agent concentrate to extinguish fire. Foaming effectiveness was determined based on droplet diameter and droplet density measured by using a mist blower TASCO MD-150. A portable foam eductor was used in fire extinguishment test.

3. Results and Discussions

3.1. Formulation of Foaming Agent Concentrate

The process of foaming agent concentrate formulation and homogenation at 25 liter scale is depicted in Figure 1. This formulation stage resulted in many formulas of foaming agent concentrate with rather sticky and liquid consistency. Seven formulas including NFA, NF3, NF5, NF7, NF15, NF17, and NF18 were selected as they had relatively better foam stability as their foam could stay intact until day 3. In addition to these 7 formulas, parameter testing was also done to AFFF, a commercial fire extinguishment chemical available in the market which was used as control. In the test, foaming agent concentrate was dissolved in water at the concentration of 1% and results of this test are listed in Table 1.

The value range of 30-91% was obtained in the measurement of foam stability of the seven formulas on day 3. The formulas of foaming agent concentrate had significantly higher foam stability than commercial AFFF formula did (0%). Foam stability of commercial AFFF dropped drastically to 12.8% on day 1, 5.3% on day 2, and 0% on day 3. NF5 formula was found to have the highest foam stability (91%) followed by NF17 (88%).

Figure 1. Formulation and homogenation process of foaming agent concentrate at 25 liter scale

Table 1. Results of parameter analysis of foaming agent concentrate dissolved in 1% water and commercial product

Parameter	Formula of Foaming Agent Concentrate							AFFF
	NFA	NF3	NF5	NF7	NF15	NF17	NF18	
Foam stability (%, day 3)	58	83	91	61	77	88	30	0
Foaming capability(%)	479	314	288	318	503	372	310	204
Surface tension (dyne/cm)	22.13	19.89	21.19	20.53	19.68	25.05	19.74	19.81
Interfacial tension (dyne/cm)	4.2	0.54	0.86	2.23	1.12	1.67	1.61	0.55
Viscosity (cP):								
- 1%	1.04	1.03	1.00	1.05	1.02	1.02	1.04	0.99
- 100%	2.64	3.64	2.34	224.33	253.27	7.15	52.79	2.71
Contact angle (°):								
- Minute 0	63.79	58.16	63.49	61.46	55.09	54.77	53.75	60.41
- Minute 10	22.42	19.52	11.84	17.47	15.27	19.70	16.99	25.51
Density (g/cm3)	0.99586	0.99600	0.99608	0.99597	0.99612	0.99601	0.99601	0.99577
Specific gravity	1.00021	1.00034	1.00043	1.00032	1.00046	1.00036	1.00036	1.00007

Foaming ability of the seven formulas of foaming agent concentrate was 288-503%. These figures were higher than that of commercial AFFF (204%). Surface tension of formulas of foaming agent concentrate was 19.68–25.05 dyne/cm. These were relatively similar to that of commercial AFFF (19.81 dyne/cm). The lowest surface tension (19.68 dyne/cm) was found in NF15 formula and the highest (25.05 dyne/cm) was found in NF17 formula. This highest figure was still within the requirements of class A foam [3]. At 1% concentration, the interfacial tension of AFFF foam and AFFF/PEO foam was about 52-63 dyne/cm, and increment of the concentration of foaming agent concentrate gave significant effects on the reduction of interfacial tension [8].

Interfacial tension of formulas of foaming agent concentrate was 0.54–4.20 dyne/cm. These figures were almost similar and close to that of AFFF product (0.55 dyne/cm). The seven formulas of foaming agent concentrate were rather thick and liquid with viscosity levels of 2.34-2.53 cP. Meanwhile, AFFF product was liquid with a viscosity level of 2.71 cP. Only 4 formulas including NFA, NF3, NF5, and NF17 were liquid similar to AFFF product. At a solution concentration of 1%, the viscosity levels of formulas of foaming agent concentrate were about 1.00-1.05 cP and that of AFFF product was 0.99 cP. NF5 formula was found to have a viscosity level closest to that of AFFF product.

Contact angles of formulas of foaming agent concentrate were 53.75-63.78° at minute 0 and 11.84 – 22.42° at minute 10. For AFFF product, the contact angles were 60.41° at minute 0 and 25.51° at minute 10. Higher reduction of contact angle of foaming agent concentration solution at minute 10 indicated that the concentrate solution had stronger ability to penetrate into the media than AFFF product. Density levels (0.99586 – 0.99612 g/cm^3) of foaming agent concentrate formulas were slightly higher than that of AFFF product (0.99577 g/cm^3). However, these figures were considerably lower than that of class A foam concentrate (1.025 g/ml) [3].

Specific gravity of foaming agent concentrate ranged from 1.00021 to 1.00046. These figures were slightly higher than that of AFFF commercial product (1.00007). However, these figures were considerably lower than that of class A foam concentrate (1.0240) [3].

3.2. Performance Test of Foaming Agent Concentrate for Fire Extinguishment

Determination of parameters of foaming effectiveness of foaming agents is important to do before the agents are applied in fire extinguishment. In principle, fire extinguishment is covering or filling a surface and porous space with a foaming agent liquid to avoid contact between oxygen and fire or coals of fire so that the fire or coals of fire can be extinguished. Fire extinguishment by using a foaming agent will be more effective with finer droplet size and higher droplet density. Results of foaming effectiveness analysis showed that at constantly maintained pressure of 7.0 kgf/cm^2 and effective spraying height of 20-43 cm, NF5 foaming agent formula produced the smallest droplet diameter of 0.14 mm and the highest droplet density of 3056 droplets/cm^2. The graphs of droplet diameter and droplet density of various concentration of foaming agent solution are depicted in Figures 2 and 3, respectively.

The application test of foaming agent as fire extinguisher was conducted by using a portable foam eductor. The eductor was connected by a hose to water source and a foaming agent concentrate collecting tank. The flow rate of foaming agent concentrate was adjusted to about 1 L/7 seconds and water flow rate to about 5 L/second. Spraying was then done as shown in Figure 4. Results of fire extinguishment test showed that fire was put out rapidly after foam solution was sprayed into the source of fire.

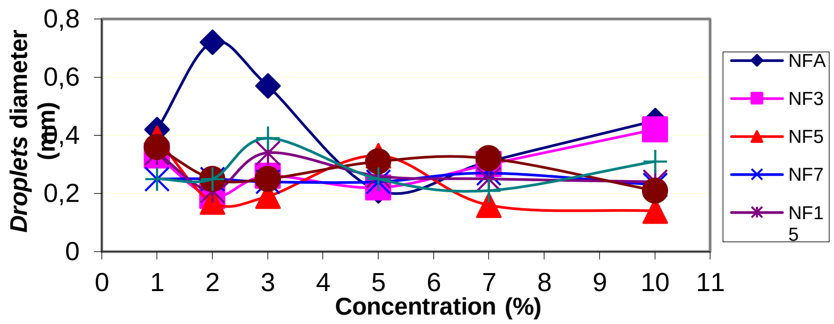

Figure 2. Graph of droplet diameter in various concentrations of foaming agent solution

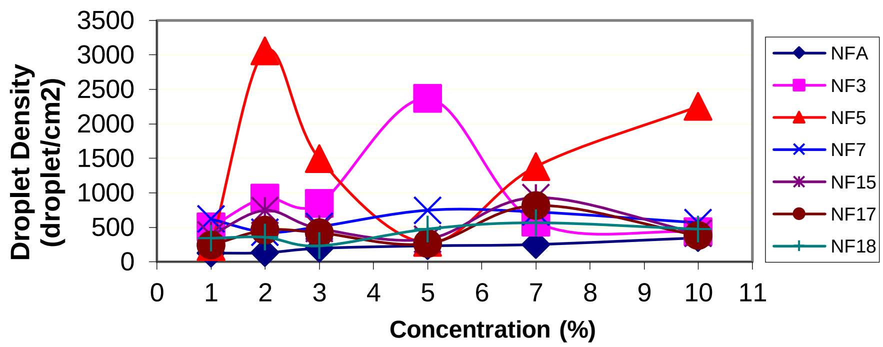

Figure 3. Graph of droplet densityin various concentrations of foaming agent solution

Figure 4. Fire extinguishment trial by using resulted formulas of foaming agent concentrates

4. Conclusions

The foaming agent concentrate products were produced in a rather paste and liquid forms with viscosity levels of about 2.34–253 cP. Results of formula analysis of foaming agent concentrates dissolved in 1% water had a range of foam stability levels of 30-91%, foaming ability of 288-503%, surface tension of 19.68-25.05 dyne/cm, interfacial tension of 0.54–4.20 dyne/cm, viscosity level of 1.00-1.05 cP, contact angle of 53.75-63.79° at minute 0 and 11.84-22.42° at minute 10, density of 0.99586–0.99612 g/cm^3, and specific gravity of 1.00021-1.00046. Based on foam stability, foaming ability, and surface tension parameters, the best foaming agent concentrate products were NF5 and NF17 formulas which also had better performance than commercial product did. NF5 formula had the smallest droplet diameter of 0.14 mm and the highest droplet density of 3056 droplets/cm^2.

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