Production of long-term flame-retardant from rice husk

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PROJECT CERTIFICATE

Report Title Production of long-term flame-retardant from rice husk

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ABSTRACT

This study focuses on using agricultural waste as a crucial component of an eco-friendly, reasonably priced flame retardant to deal with the rising frequency of wildfires. Diammonium phosphate (DAP), magnesium hydroxide, aluminum hydroxide, and guar gum are mixed with silica, which is obtained from waste, to create an innovative flame retardant. The objective is to turn waste into a useful product, enhancing wildfire management and reducing the impact on the environment. Compared to other options, these flame-retardant promises to improve performance and convenience of preparation while costing less. To maximize this potential idea, more research and development are needed.

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We’re grateful to Asst. Prof. Dr. Nuttapol Lerkasemsan very much for his help with this project. His deep understanding and smart ideas have made a big difference. He always encouraged me and made me want to do better.

Guidance is more than just telling someone what to do. It's about helping them think better and work harder. Asst. Prof. Dr. Lerkasemsan did that for us. He showed me how to think like a scientist and work like a researcher. His support was very important to me. When things got tough, he helped me stay positive and focused. His feedback was always useful and helped me improve. Asst. Prof. Dr. Lerkasemsan made sure we had everything we needed to succeed. He cares about learning and discovery, which helped us a lot in our project. We are thankful for the chance to learn from such a great person. His help has not only made this project better but also helped us grow as a person.

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CHAPTER I

INTRODUCTION

Introduction

1.1. Background

Forests are natural resources that are valuable to humans in many ways. Forests are the source of four fundamental factors used in human life which enable human beings to live. In addition, forests are home to many living things, both wildlife, and plants. Nowadays, the rapid increase in population has led to the expansion of the community. Therefore, the demand for wood for use, the need for agricultural land for living, for industry, building reservoirs, and cutting roads, so there are more and more. It is causing many forest areas to be destroyed or deteriorated. In addition to these reasons, the forest fire problem also greatly contributed to the deterioration of forest resources because nowadays wildfires that occur every year are increasing in intensity and frequency. More frequently causing the forest to be unable to recover and catch up with the natural cycle. Forest fires affect other parts of the environment. Also, to the soil, water, air, wildlife and small creatures in the forest, tourist attractions, human life, and property including the world's climate.

In the current forest fire situation, except from being one of the key causes of forest loss, it also affects other environments such as soil, water, and air as well. In academic terms, forest fires are normal phenomena that occur in natural cycles to make the roots of certain plants grow. According to the natural life cycle, however, it is now considered to be a significant degradation of forest resources and economic development in the form of forest use. Then, the balance of the forest changed until the weather dried up. As a result, the wildfire phenomenon that used to occur naturally has changed from a 10-year cycle, becoming more frequent almost every year, and being aggravated by human actions in the present. unable to recover.

The behavior of fires cannot be predicted or assessed accurately and precisely. But how a fire behaves will depend on the fire's surroundings. The important factor is the environment that controls the fire which is fuel, air, and topography (temperature).

1.2. Objectives

- To study the properties and mechanism of nano-silica.
- To find a method for the extraction of nano-silica to achieve the highest purity.
- To increase the value of agricultural by-products to be used for benefit.
- To develop and produce long-term forest fire retardant that does not affect the environment.

1.3. Scope of work

- Nano-silica extraction from agricultural waste, the raw material used is rice husks.
- Use equipment and chemicals that do not have an impact on the environment, animals, and humans. Including, long-term forest fire retardants must be able to protect long-term enough for the dry weather and the most likely to cause forest fires.
- Use raw materials and substances that can be found in Thailand so that they can be easily obtained and at the lowest production cost possible.

1.4. Expect output

- Nano-silica can be extracted from rice husks cost-effectively and purity is comparable to the standard.
- Highly effective long-term fire suppression, it can protect for approximately 2-3 months and does not cause toxicity or harm to the environment, animals, or humans.

CHAPTER II

LITERATURE REVIEWS

Literature reviews

2.1. Rice husk

Rice husks are by-products of rice milling (Oryza sativa) and are often regarded as "waste". The rice husk is the hard shell that covers the outermost part of the rice grain which in biology is a lemma. It has low nutritional value compared to the endosperm; the rice husk leaves the seed after the first milling process. Rice husks contain cellulose, hemicellulose, lignin, and ash, and are high in silica in the ash. Rice husk is insoluble in water, chemically stable, and resistant to force. Therefore, it is a good absorbent in the treatment of wastewater containing heavy metals. Rice husk heavy metal removal has been reported to work with cadmium, lead, zinc, copper, cobalt, nickel, and silver. It can be used both in forms that do and do not react with chemicals. Chemicals commonly used to react with rice husks to absorb more metals are sodium hydroxide sodium carbonate and epichlorohydrin [3].

Figure 1 Rice husk (rice hull)

In addition to using rice husks as fuel, they can also be mixed with other materials to make construction materials. Rice husks are also used to produce Rice Husk Ash. The main component of rice husk ash is silica (SiO_2) which can be purified by a chemical process with high-temperature sintering. Silica in rice husk ash is crystalline silica, crystalline silica can be subdivided into several types according to their different shapes, crystalline characteristics, and density of silica. There are many shapes of crystals such as triangles, squares, hexagons, cubes, long lines, and amorphous silica.

2.2. Silicon dioxide (SiO_2)

Silicon dioxide, also known as silica, is an oxide of silicon with a chemical formula. It is mostly found in nature as crystals and living things. In many parts of the world, silica is an important component of sand. Silica is one of the most complex and abundant groups of materials. It is a compound of many minerals and is a synthetic product. Notable examples include fused quartz, fumed silica, silica gel, and aerogels, used in structural materials microelectronics (as an electrical insulator) and as a component in the food and pharmaceutical industry.

Figure 2 A) Structure of Silicon dioxide. B) SEM micrograph of nano silica.

2.3. Guar gum

Guar gum, also known as Guaran, is derived from legumes known as guar beans. It is a polysaccharide or a long chain of carbohydrate molecules that are joined together and composed of two sugars known as mannose and galactose. It is mainly used as a food additive in many processed foods. It is particularly useful in food production because it is a water-soluble and absorbent product, thickening, gelling, and improving adhesion. It is accepted to be safe to use in certain amounts in various food products. And when mixed with water or liquid, it is often thickened to create a texture-like gel that holds well at temperature or pressure. In other words, it is a substance that improves viscosity and is resistant to pH [2].

Figure 3 A) Guar gum powder. B) Guar bean or cluster bean.

2.4. Sodium silicate (Na_2SiO_3)

Figure 4 Sodium silicate solution.

Sodium silicate as a compound Sodium oxide, silica, and water are mixed in different ratios thus making it qualified to be used extensively. Sodium silicate has basic properties, is used as a pH control agent, and can prevent corrosion well. With sodium silicate solution containing strong silica and having adhesion properties as well as being able to react with various compounds, small particles easily penetrate surfaces, pores, and small gaps. Sodium silicate solution is therefore used in a variety of construction industries. Sodium silicate has the advantage of forming a thin film that dries quickly and is not flammable [10].

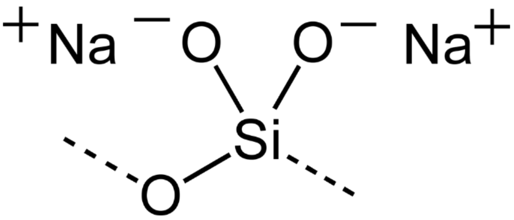

Figure 5 Structure of Sodium silicate.

2.5. Magnesium hydroxide ($Mg(OH)_2$)

Magnesium hydroxide is an inorganic compound, found naturally in the form of a brucite mineral. Magnesium hydroxide can be used as an antacid or laxative in either oral or chewable suspension form. Magnesium hydroxide also has smoke-suppressant and flame-retardant properties. Therefore, is commercially used as a flame retardant.

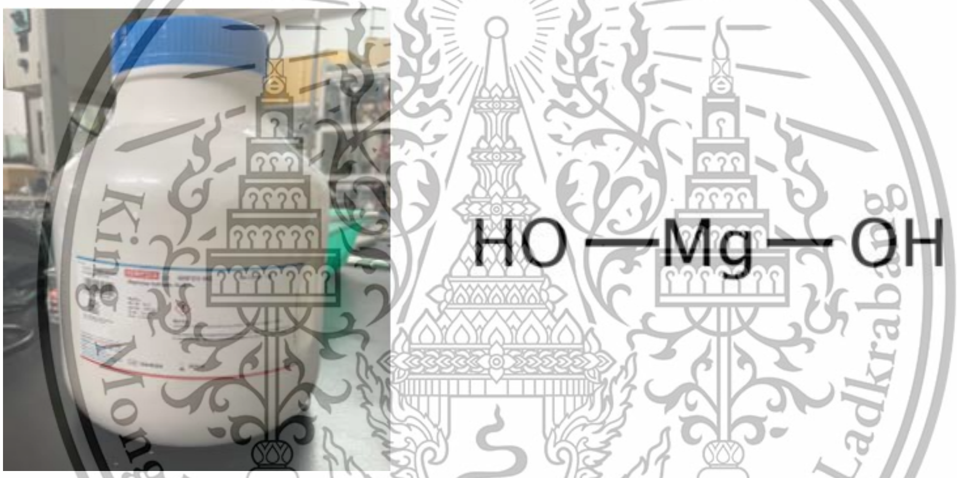

Figure 6 A) Magnesium hydroxide. B) Structure of Magnesium hydroxide.

Physical Properties of Magnesium Hydroxide

- The molecular weight of Magnesium Hydroxide is fifty-eight.
- It is mostly white in color but is also found in blue and yellow color.
- It has extremely low solubility in water or any polar solvent.
- The melting point is around 330° to 350° C.

Chemical Properties of Magnesium Hydroxide

- It is highly flammable in normal temperatures; it burns in air with a bright white light.
- Upon heating with Halogens, it reacts with Halogen.
- When it reacts with HCl, it forms magnesium Chloride, a colorless water-absorbing material.
- Magnesium Oxide is formed by roasting magnesium carbonate or magnesium hydroxide.
- The pH of magnesium hydroxide is around 10.

2.6. Aluminum hydroxide ($Al(OH)_3$)

Aluminum hydroxide has functions of flame retardant, smoke suppression, and containment, and is an inert chemical, non-toxic, and has no secondary pollution. Therefore, it is called a "non-polluting flame retardant". When heated to about 200-300 °C, aluminum hydroxide begins to decompose into water vapor, which absorbs heat and inhibits temperature increase [4].

Figure 7 A) Aluminum hydroxide. B) Structure of Aluminum hydroxide.

In addition, if the aluminum hydroxide is dried, aluminum oxide forms a protective film on the surface of combustible materials to reduce the exposure to oxygen and prevent combustion.

2.7. Mechanism of flame-retardant

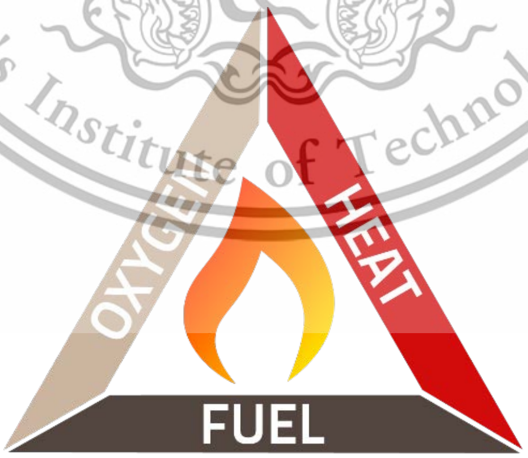

Figure 8 Fire triangle

Cooling an endothermic process is activated by our flame retardants that lowers the temperature, in other words, cools the surface to a temperature below the flash point. In which the cooling is to reduce the fire factor, one factor is the matter of heat.

Formation of a protective layer: When spraying fire retardants, the fire retardant will adhere to the surface of the trees in the forest. And when it cools down, it will begin to form a layer like a shield. This allows it to stay stable on the surface. In addition to this adhesion, it is possible to reduce the temperature (heat transfer) of the surface area. It can also reduce the amount of oxygen that will be exposed to some as well. In which oxygen is another factor in the occurrence of a fire.

Soaking deionized water

$$2Na(s) + 2H_2O(l) \rightarrow 2Na^+(aq) + 2OH^-(aq) + H_2(g)$$

$$2K(s) + 2H_2O(l) \rightarrow 2K^+(aq) + 2OH^-(aq) + H_2(g)$$

Soaking hydrochloric acid

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

$$Ca(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2(g)$$

$$Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$$

$$Al(s) + 2HCl(aq) \rightarrow AlCl_2(aq) + H_2(g)$$

Sodium Silicate

$$SiO_2(s) + 2NaOH(aq) \rightarrow Na_2SiO_3(aq) + H_2O(l)$$

2.8. Behavior of coating

The spreading coefficient used to describe the uniform film and the equation shown below where γ_{S0} is the surface tension the of dry surface, γ_{SL} is the surface tension of solid-liquid interface, and γ_{LV} is surface tension the of liquid-vapor interface [1][2]. If $S < 0$, the flame-retardant will only partially wet on surface but if $S \geq 0$, the flame-retardant form stable films which is uniform coating for the flame-retardant and vegetation. while γ_{SL} is cannot measure for solid-liquid interface [5][6].

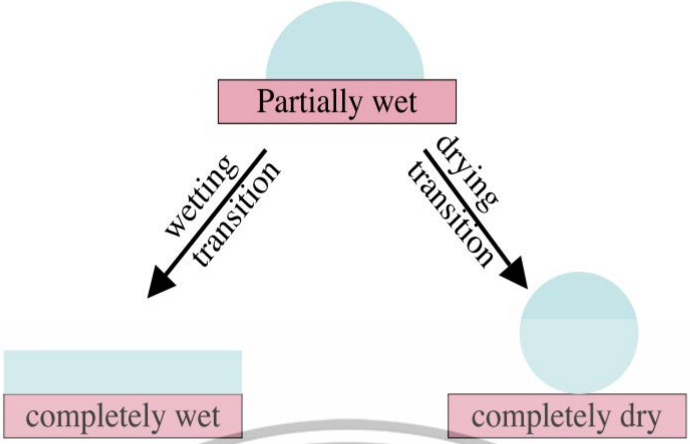

Figure 9 Behavior of flame-retardant coating.

$$S=\gamma_{S0}-\gamma_{SL}-\gamma_{LV}$$

2.9. Standard for long term flame retardant

The management of public lands in national forests and grasslands is the responsibility of the United States Forest Service (USFS), a government organization located inside the United States Department of Agriculture. The sustainable management of these lands, which includes managing the wildlife habitats and fish along with human recreational, belongs within the responsibility of the USFS. The USFS is important in organizing resources and reacting to wildfires in national forests and grasslands, which is another important function it performs in putting out wildfires.

The United States Forest Service (USFS) sets standards for long-term wildfire flame retardants that are applied on public lands to fight wildfires. These requirements guarantee that long-term fire retardants are efficient in controlling wildfires and safe for the environment and human health. The specification of this standard is shown in the table below.

Table 1 Summary standard of long-term flame retardant

Specification	Description
Chemical Composition	Ammonium polyphosphate (Not exceed 80%)
Performance	Reduce fire spread by at least 75%, increase time to reach treated area by at least 5 times
Environmental Impact	Safe for vegetation, wildlife, and water resources
Health and Safety	Meet health and safety standards
Testing Conditions	Dry fuel, moderate wind speeds (0-20 mph), horizontal application, laboratory, and field testing
Biodegradability	Long-term fire retardants must be biodegradable and not persist in the environment.
Containment and Disposal	Long-term fire retardants must be contained and disposed of properly to prevent environmental contamination.

The USFS can confirm that long-term wildfire flame retardants are efficient at preventing the spread of wildfires and giving firefighters the time, they need to protect lives and property while also being secure for the environment and human health by testing them under these typical conditions.

2.10. Reaction of flame retardant

When exposed to heat, the interaction of sodium silicate (Na_2SiO_3) and diammonium phosphate (DAP) will generates a protective barrier and releases non-flammable gases to absorb heat from the surrounding environment, which helps to prevent or slow down the spread of fire. Our flame retardant can be summarized into 3 stages.

2.10.1. Dehydration reaction

When heat is given to the flame-retardant mixture, the sodium silicate and diammonium phosphate loses water and dehydrate. This process produces the formation of a solid, glassy, and highly viscous coating on the treated surface of the material, which provides as a protective barrier against flames. This protective layer acts as a barrier between the material and the heat and flames, reducing the combustion process and slowing the rate of combustion processes.

2.10.2. Endothermic reaction

The endothermic reaction in the context of sodium silicate (Na_2SiO_3) and diammonium phosphate (DAP) flame retardants refers to the decomposition of diammonium phosphate when exposed to heat. DAP decomposes into ammonia (NH_3) and phosphoric acid (H_3PO_4) when heated. The ammonia generated during the process also reduces the amount of oxygen in the nearby area, which makes it more difficult for the fire to keep burning. A thermally stable and fire-resistant inorganic phosphate-silicate glass is created when the generated phosphoric acid combines with the sodium silicate.

$$(NH_4)_2HPO_4(s) \longrightarrow 2NH_4(g)+H_3PO_4(l)$$

This decomposition reaction is endothermic, which means it absorbs heat from the surroundings. As a result, the temperature of the treated material and the surrounding area decreases, which helps to slow or stop the spread of fire. The endothermic process lowers the rate of combustion and may even extinguish the flames by reducing the temperature and removing heat generated.

2.10.3. Reaction between phosphoric acid and sodium silicate

The reaction between phosphoric acid (H_3PO_4) and sodium silicate (Na_2SiO_3) affects the flame-retardant properties of a sodium silicate and diammonium phosphate (DAP) combination significantly. When these two chemicals combine, they generate a thermally stable and fire-resistant inorganic phosphate-silicate glass that creates a protective barrier on the treated surface of the material.

$$H_3PO_4(l)+Na_2SiO_3(s) \longrightarrow NaH_2PO_4(s)+NaHSiO_3(s)$$

Phosphoric acid donates a hydrogen ion (H^+) to sodium silicate in this reaction, resulting in the creation of sodium dihydrogen phosphate (NaH_2PO_4) and sodium hydrogen silicate ($NaHSiO_3$). These chemicals combine to generate an inorganic phosphate-silicate glass layer on the surface of the treated material.

Benefit	Description
Thermal stability	The phosphate-silicate glass has a high melting point and excellent thermal stability, making it resistant to degradation at high temperatures.
Insulation	The glass layer acts as an insulating barrier between the heat source and the treated material, reducing the rate of heat transfer and slowing down the combustion process.
Suppression of flammable gases and vapors	The formation of the phosphate-silicate glass layer helps to suppress the release of flammable gases and vapors from the treated material, reducing the fuel available for the fire to spread.
Protective barrier	The inorganic phosphate-silicate glass layer provides a protective barrier on the surface of the treated material, shielding it from direct contact with the flames and heat.
Environmentally friendly	The reaction products of phosphoric acid and sodium silicate are relatively non-toxic and less harmful to the environment compared to other flame-retardant chemicals, such as halogenated compounds.

Table 2 summary of phosphate-silicate

2.10.4. Reaction of Magnesium hydroxide

Magnesium hydroxide ($Mg(OH)_2$) is a common smoke suppression and flame retardant, especially in polymer applications. It decomposes endothermically in the thermal environment, releasing water and generating magnesium oxide (MgO), a substance that is both thermally stable and fire-resistant.

$$\mathrm{Mg}\left(\mathrm{OH}\right)_2\left(\mathrm{s}\right)\longrightarrow\mathrm{MgO}\left(\mathrm{s}\right)+\mathrm{H_2O(g)}$$

Magnesium hydroxide can enhance the mixture overall flame-retardant characteristics when it is added to the reaction between sodium silicate and phosphoric acid. Magnesium hydroxide can add thermal stability, heat absorption, and flame suppression to the phosphate-silicate glass layer created by the reaction between sodium silicate and phosphoric acid. These components may work well together to make a flame-retardant solution. In addition, the surface of the treated material generates a layer of protection from magnesium oxide that provides as a shield against heat and flames. By reducing combustible gases and vapors, it also prevents their release, further preventing the spread of fire. And the effect of adding too much Magnesium hydroxide much shown on the table below.

Table 3 Summarizes of magnesium hydroxide.

Effect	**Explanation**
Viscosity	Excessive $Mg(OH)_2$ may make the mixture thicker and harder to apply evenly, affecting its performance.
Compatibility	Too much $Mg(OH)_2$ can cause compatibility issues with other components, leading to phase separation or undesirable precipitates.
Reduced Effectiveness	Overloading the mixture with $Mg(OH)_2$ may disrupt the balance of reactions, hindering flame retardant performance.
Application	Excessive $Mg(OH)_2$ can lead to difficulties in mixing, spraying, or adhering the mixture to the material surface.
Cost Implications	Using too much $Mg(OH)_2$ may increase material costs and potentially reduce the effectiveness of the flame-retardant system.

2.10.5. Reaction of Aluminum hydroxide

Aluminum hydroxide (Al(OH)3) can also be added to a flame-retardant mixture containing sodium silicate (Na2SiO3) and phosphoric acid (H3PO4). Aluminum hydroxide is a common flame retardant and smoke suppressant in many applications, including polymers and textiles, just like magnesium hydroxide.

$$2Al\left(OH\right)_3(s) \longrightarrow Al_2O_3\ \left(s\right) + 3H_2O(g)$$

The endothermic decomposition reaction of aluminum hydroxide decreases the rate of heat transfer and slows the combustion process by absorbing heat from its surroundings. A protective layer made of aluminum oxide also forms on the surface of the treated material, acting as a shield to protect it from heat and flames. By reducing combustible gases and vapors, it also prevents their emission, further preventing the spread of fire.

However, while producing a flame-retardant combination including sodium silicate, phosphoric acid, and aluminum hydroxide, it is important to consider the compatibility of the components and the specific application requirements, similar to magnesium hydroxide. To achieve the appropriate flame-retardant qualities, it may be essential to alter the chemical concentrations and ratios. The same issues that might occur from adding too much magnesium hydroxide can also occur from adding too much aluminum hydroxide, including changes in viscosity and consistency, compatibility issues, decreased effectiveness, application difficulties, and financial consequences. To ensure best performance, it is important to maintain the components in the flame-retardant mixture in the right balance.

Table 4 Summarizes of Aluminum hydroxide.

Effect	**Explanation**
Viscosity	Excessive Al(OH)3 may make the mixture thicker and harder to apply evenly, affecting its performance.
Compatibility	Too much Al(OH)3 can cause compatibility issues with other components, leading to phase separation or undesirable precipitates.
Reduced Effectiveness	Overloading the mixture with Al(OH)3 may disrupt the balance of reactions, hindering flame retardant performance.
Application	Excessive Al(OH)3 can lead to difficulties in mixing, spraying, or adhering the mixture to the material surface.
Cost Implications	Using too much Al(OH)3 may increase material costs and potentially reduce the effectiveness of the flame-retardant system.

2.11. Comparison of Magnesium hydroxide and Aluminum hydroxide

Table 5 Comparison between Magnesium hydroxide and Aluminum hydroxide.

Additive	Decomposition Temperature	Thermal Stability	Effectiveness as Smoke Suppressant	Protective Layer Formation
Magnesium Hydroxide $(Mg(OH)2)$	~ 300 - 330°C	Good	Moderate	Formation of magnesium oxide (MgO)
Aluminum Hydroxide $(Al(OH)3)$	~ 180 - 220°C	Good	Good	Formation of aluminum oxide $(Al2O3)$

This table compares the effectiveness of magnesium hydroxide and aluminum hydroxide as flame retardant additives, considering factors including decomposition temperature, thermal stability, smoke suppression, and the creation of protective layers. However, depending on the use and the performance objectives, the appropriate performance characteristics of the two additives may vary.

2.12. Environmental and Safety

Table 6 Summarizes of environmental and safety.

Component	Environmental Impact	Safety Considerations
Sodium Silicate	Low toxicity, generally considered environmentally friendly	Non-toxic, but avoid skin and eye contact; wear protective clothing
Phosphoric Acid	Can contribute to eutrophication if released in large amounts	Corrosive; wear eye protection, gloves, and protective clothing; ensure proper ventilation
Magnesium Hydroxide	Low environmental impact, non-toxic, and biodegradable	Low toxicity, but avoid inhalation and contact with skin and eyes; wear protective clothing
Aluminum Hydroxide	Low environmental impact, non-toxic, and biodegradable	Low toxicity, but avoid inhalation and contact with skin and eyes; wear protective clothing
DAP (Diammonium Phosphate)	May contribute to eutrophication and nutrient pollution if released in large amounts	Low toxicity; avoid inhalation, skin, and eye contact; wear protective clothing

The environmental consequences and safety consequences of the flame-retardant solution, which consists of sodium silicate, phosphoric acid, magnesium hydroxide, aluminum hydroxide, and diammonium phosphate (DAP), vary. Due to their low toxicity and biodegradability, sodium silicate, magnesium hydroxide, and aluminum hydroxide are considered as environmentally friendly chemicals. On the other hand, phosphoric acid and DAP may cause eutrophication if they are released in large amounts. To reduce hazards during use, all components require proper handling, protective gear, and adherence to safety guidelines. To achieve optimal flame-retardant effectiveness while minimizing potential environmental and safety issues, the concentrations of these components must be adjusted.

Sodium silicate, phosphoric acid, DAP (diammonium phosphate), magnesium hydroxide, and aluminum hydroxide are the components of the flame-retardant system. When added to different materials, these chemicals combine to improve fire resistance and reduce flammability. When mixed, sodium silicate, phosphoric acid, and DAP create a barrier that works as a barrier to stop the spread of flames. Phosphoric acid and sodium silicate perform an endothermic reaction that absorbs heat and increases dehydration, which reduces the availability of flammable gases and improves flame suppression. Magnesium hydroxide and aluminum hydroxide can be used in addition to the primary components to further enhance the flame-retardant performance. Both additions increase endothermic decomposition, which results in the release of water vapor. This release of water vapor helps to cool the surroundings and reduces the concentration of flammable gases, which makes it more difficult for a fire to spread. Moreover, these additions produce protective layers of aluminum oxide (Al_2O_3) and magnesium oxide (MgO), respectively, which can work as heat barriers and increase flammability.

The correct dealing, storage, and disposal procedures should be followed to ensure the safe and efficient use of this entire flame-retardant system. When handling these chemicals, protective clothes such gloves, goggles, and coveralls should be provided, and there should be enough airflow supplied. The perfect formulation will vary depending on the substance being treated and the desired level of flammability, so it is crucial to perform tests and studies to determine the optimal concentration of each component for a specific application. It is possible to achieve efficient fire protection while reducing the effects on the environment and human health by carefully evaluating the composition and application of this flame-retardant solution.

CHAPTER III

RESEARCH METHODOLOGY

Research Methodology

3.1. Chemical and Equipment

3.1.1. Raw material

- Rice Husk

3.1.2. Chemicals

- Guar Gum
- Distillate water
- Deionized water
- Ethanol
- Silicon dioxide (SiO_3)
- Hydrochloric acid (HCl)
- Sodium hydroxide (NaOH)
- Ammonium hydroxide (NH_4OH)
- Aluminum hydroxide ($Al(OH)_3$)
- Magnesium hydroxide ($Mg(OH)_2$)

3.1.3. Equipment

- Oven
- Mortar
- Reflux
- Cylinder
- Centrifuge
- Crucible
- Beaker (50, 100, 500, 1000 ml)
- Grass reactor
- pH meter paper
- Electric sprayer (
- Drone (dji mini-1)
- Thermal image meter (Fluke TiS75+ thermal imager)

3.2. Methods

3.2.1. Preparation of Rice husk

Figure 10 Soaking rice husk with deionized water

The rice husk was separated by hand and pretreatment by washing with distillate water several times and dried in the oven at 110 °C for 3 hours. Soak the rice husk in deionized water for 24 hours. Dried with oven at 110 °C for 3 hours [3].

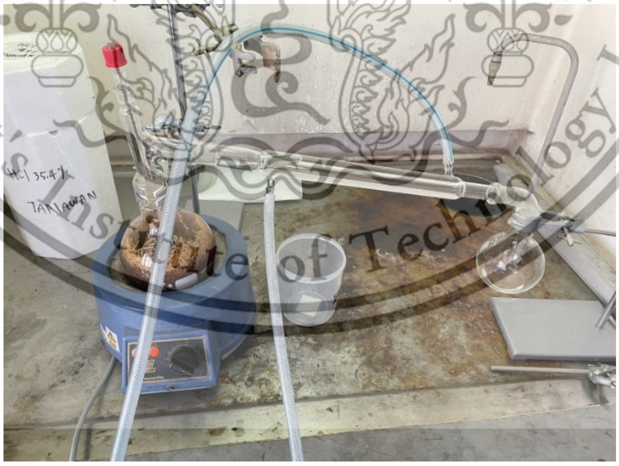

Figure *11* Soaking rice husk in hydrochloric acid

Then weight 100 g of rice husk, add 600 ml concentration 8% of HCl solution into a round bottom flask, and heat with a heating mantle at 110 °C for 3 hours. The refluxed rice husk was washed with distillate water until pH equal to 7 and dried in the oven at 100 °C for 3 hours.

3.2.2. Incinerate of Rice husk

Figure 12 Incinerate rice husk in electric furnace

Prepare rice husk to incinerate by weight 10 g of rice husk and put into a crucible 10 cm. Preheat the electric furnace to 200 °C. Then put the crucible into the electric furnace and heated to 650 °C for 3 hours. After incinerating keep it cool down and take the crucible out of the furnace. The residue of the rice husk formed white silica was obtained.

Figure *13* White silica was obtained after incinerating.

The silica was gathered and ground with mortar until white silica became powder. Soak ethanol in a centrifuge tube and mix with vortex and leave static for 10-15 minutes at room temperature and centrifuge at 6000 rpm for 5 minutes. Pour ethanol out of the centrifuge.

Figure 14 Grounding white silica until become powder with mortar

Then refrigerate for 1-2 hours. The cleaned rice husk was pulverized. Silica was mixed with dilute hydrochloric acid in refluxing 500 ml and heated to 120 °C for 2-3 hours. After the process, the silica was separated and extracted with vacuum filtration. Wash the solids until pH equal to 7 and dried at 110 °C for 2-3 hours to prepare silica.

3.2.3. Preparation of Sodium Hydroxide (NaOH)

To make NaOH 1, 2, and 3 M solution for 1 liter respectively. Prepare NaOH solution by weight 40, 80, and 120 g of NaOH and prepare deionized water 500 ml then slowly add NaOH to 500 ml of deionized water. When the solution is well dissolved, put the solution into a volumetric flask and adjust the final volume of the solution to one liter.

3.2.4. Preparation of Sodium Silicate (Na_2SiO_3)

To prepare sodium silicate 5%, 10%, 15%, and 20% silicon dioxide (SiO_2). Weight silicon dioxide powder 200 g and prepare sodium hydroxide from the previous method. Heat the reactor at 60 °C then add silicon dioxide to the reactor and mixed with sodium hydroxide until silicon dioxide will dissolve in the solution, the sodium silicate 20% was obtained. Then dilute the solution to 5, 10, and 15%.

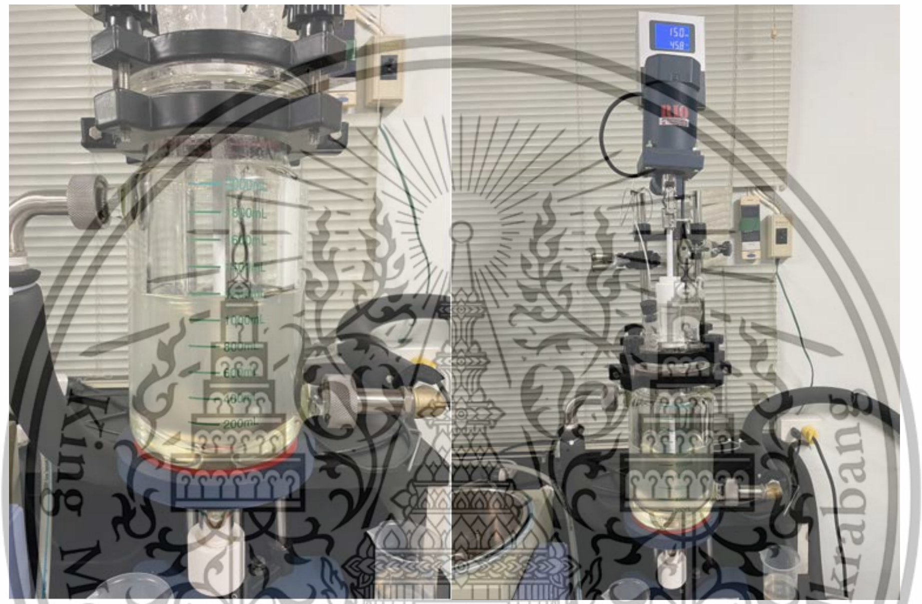

Figure 15 Processing of Sodium silicate

3.2.5. Preparation of flame retardant

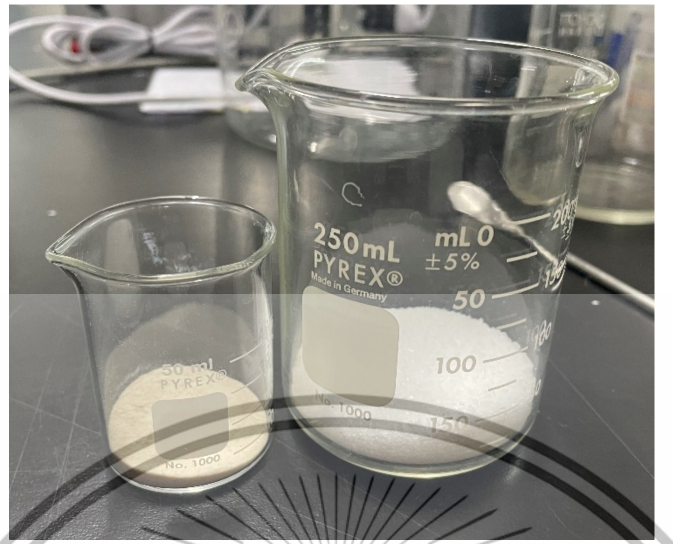

Figure 16 Guar gum and DAP

To prepare flame retardant from silicon dioxide. Particle gel was prepared by dissolving guar gum in deionized water with heating and stirring. Sodium silicate 20% was diluted to 5, 10, and 15%. Magnesium hydroxide ($Mg(OH)_2$) and Aluminum hydroxide ($Al(OH)_3$) were used for 13.5% of the solution.

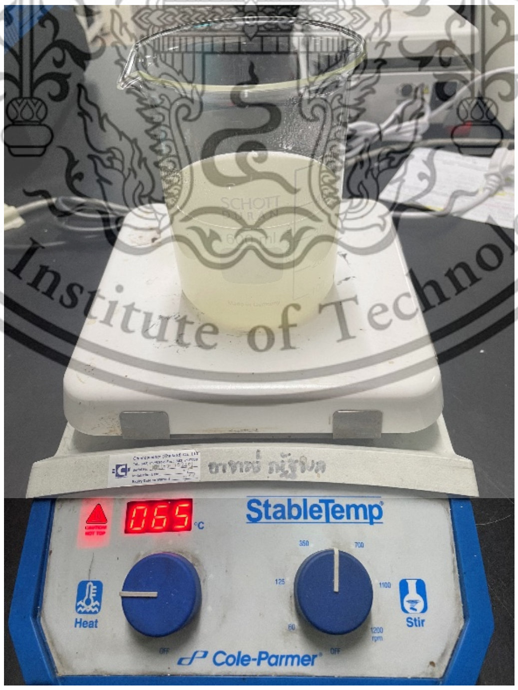

Figure 17 Mixing of flame retardant

Flame retardant was prepared by mixing guar gum solution with Magnesium hydroxide and Aluminum hydroxide was performed with heating and stirring. After mixing, leave the solution to cool down with stirring, and flame retardant was obtained.

Table 7 Sample of Flame-retardant

Flame retardant				
Sample	**Silica**	**ATH/Mg**	**CSPs (%)**	**Guar gum (%)**
1	Commercial Si	13.50%	5	4
2			10	4
3			15	4
4			20	4
5	Si from RH		5	4
6			10	4
7			15	4
8			20	4
9	Commercial SiNP		5	4
10			10	4
11			15	4
12			20	4
13	SiNP from RH		5	4
14			10	4
15			15	4
16			20	4

3.3. Testing

3.3.1. Dynamic and flow rheometric

Dynamic and flow rheometric was measured by a rheometer. The frequency sweeps were controlled in the linear viscoelastic regime from 0.1-100 rad/s. Steady-shear was performed from 0.1-100 s^{-1}.

3.3.2. Surface tension of retardant

The capillary method is a standard technique for measuring surface tension. To begin, use an appropriate solvent to clean a thin glass tube or small glass capillary tube. Fill the tube with the liquid whose surface tension you want to measure, making sure there are no air bubbles.

Figure 18 Measure height of liquid

Put the tube vertically in a beaker of the same liquid, with the bottom end barely touching the liquid surface. Capillary force causes the liquid to rise in the tube until it reaches a specific height above the liquid surface. Take the average of many measurements to get the height of the liquid in the tube. Calculate the surface tension of the liquid using the formula and compare the results to known values in the literature to validate the measurements.

3.3.3. Biodegradability

The COD and BOD of flame-retardant solution were determined to standard.

3.3.4. Viscosity test

We created an experiment with an incline plate, micropipette, timer, and ruler to test the viscosity of the flame retardant at different concentrations of guar gum. Prepare flame retardant with different guar gum concentrations first. The inclined plate needs to be set up at a 45-degree angle. Mark the beginning and finish points. Set the micropipette volume to 1000 microliters. Press the micropipette to release the sample onto the plate, then start counting for 15 seconds. Measure the fluid's distance traveled after that.

3.3.5. Evaporation time

To test evaporation time, we designed an experiment to measure the amount of time it takes for water to evaporate from a flame retardant, and we collected the sample mass every half hour to measure this. To do the experiment, start with preparing the sample by cutting pine wood into a square box for 5 pieces. Then, spray the flame retardant on the sample and measure mass of the sample. After 30 minutes measure the mass of the sample and repeat until the mass of the sample will stable.

3.3.6. Grass burns experiments

Make grass plots 1×1 m and 5×5 m. Prepare grass after plot by dried a grass for 1 day. After making the plot, spray flame retardant on the grass for each plot with different condition with the electric sprayer and leave the circle in the middle to be a fuel then leave in until the flame retardant dried.

Figure 19 Before and after burning test

For making 5×5 meter, do the same as 1×1 meter but in the step of spray we change from make a uncoating in the middle to spray half by half because on 5×5 meter we can collect the result with different wind speed, and we can get the result of flame spread for treated and untreated sample. For the ignition, 1×1 meter we used the hand torch to ignite the grass in the middle that we left to be the fuel. To make a flame spread to the treated area on the 5x5 meter, we ignite on the side that does not spray for 3 points. Then gather the data using a drone.

3.3.7. One month test of treated pine wood

Prepare a square box from out pine wood by cutting. Then, weight mass before test and spray the flame retardant to the pine wood and prepare one box with untreated wood. Leave the sample dry in the oven at 60 C or leave it in normal atmospheric until retardant dried. Make a note of the date that we will test each pine wood. Also, keep the sample in a normal environment.

Figure 20 Sample for testing 1 month performance

3.3.8. Weight loss test of pine wood

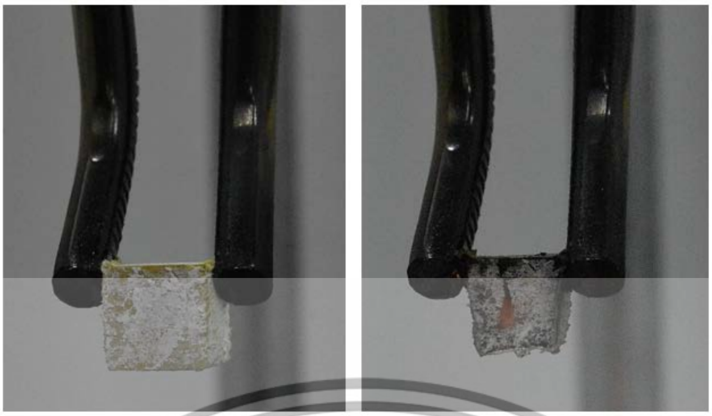

Figure 21 Before and after burning test

To test the sample, use a stand to hold it at the same height as the test, then burn the sample for 30 seconds before turning off the light and leaving it until no smoke is released.

Figure 22 Measure weight loss

After the sample cooldown, weight mass of residue a sample. Then the weight loss is measured. Repeat for each sample.

Table 8 Solution of flame retardant

Sample	**DAP (%)**	**Na_2SiO_3 (%)**	**Salt (%)**	**Guar gum (%)**
1	10	-	-	0.2
2	10	0.5	-	0.2
3	10	1	-	0.2
4	10	2	-	0.2
5	13.5	-	-	0.2
6	13.5	0.5	-	0.2
7	13.5	0.75	-	0.2
8	13.5	1	-	0.2
9	13.5	2	-	0.2
10	13.5	3	-	0.2
11	13.5	0.5	0.1	0.2
12	13.5	0.5	0.5	0.2
13	13.5	0.75	0.1	0.2
14	13.5	0.75	0.5	0.2

CHAPTER IV

RESULT

Result

4.1. Properties

4.1.1. Purity of Silicon dioxide

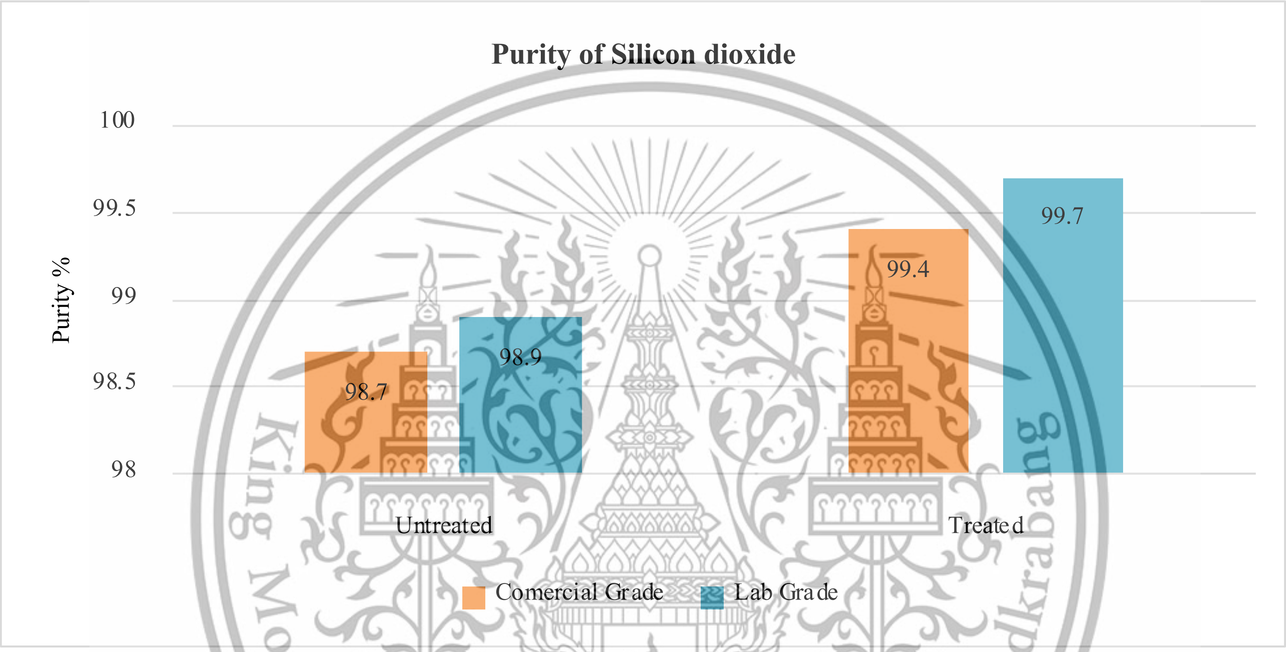

Figure 23 Graph purity of silicon dioxide

The difference between lab-grade and commercial-grade chemicals. Comparing commercial grade and lab grade chemicals, Lab grade has a higher purity level around 98.9% in this case, while commercial grade has lower purity level around 98.7% in this case. Impurities in commercial grade chemicals may contain amounts of other substances, compounds, or residual solvents.

If we consider silicon dioxide extraction from rice husk. In the incineration process, the organic matter has burned away but it still has inorganic compounds left. The purity of silicon dioxide also depends on the purity of the chemical that we used during extraction. If we are using commercial grade to extract the silicon dioxide, the purity will be lower than using lab grade.

After incineration, treated with HCl can help to remove the impurities because HCl is a strong acid that can dissolve or remove the impurities and metal ions. When HCl reacts with impurities it will form water-soluble salt that can be washed aways with water. When treated with commercial grade the purity of silicon dioxide increases from 98.7% to 99.4%. On the other hand, if we are treated with lab grade the purity can increase from 98.9% to 99.7%.

Using lab grade chemicals which have higher purity into the process of extraction can result in higher purity of silicon dioxide. And when treating with HCl after the incineration, can help to improve the purity by dissolving or removing the impurities that still left.

4.1.2. SEM microscope

SEM (Scanning Electron microscopy) is a technique used to obtain high resolution images of sample surface. SEM result as the figure below, we can observe such as particle size and shape of the particle. The bright and dark contrast areas in the figure are indicative of difference in election emission.

Figure 24 SEM microscope

The magnification factor of each figure is 3500 and 5000. and scale bar corresponds to 5 and 10 micrometers in real dimensions. This information can help to estimate the size of particle as the result. At the highest magnification when compared to the result from the reference at 150,000. We cannot conclude the particle size because our result has maximum at 5000x while the reference is 150,000x. And therefore, if we increase the magnification, we may assume that our results will also change. To determine the particle size and decide, we will need more information.

When we cannot estimate the particle size, as the first plan we will use the colloidal silicon dioxide as a component of flame retardant that performance of flame retardant will depend on the particle size of silicon dioxide when the particles size is smaller in can increase area of surface. So, we decided to change from silicon dioxide that keeps the moisture into the porous and it will release the moisture when exposed to heat into sodium silicate that can make barrier instead of releasing the moisture when exposed the heat.

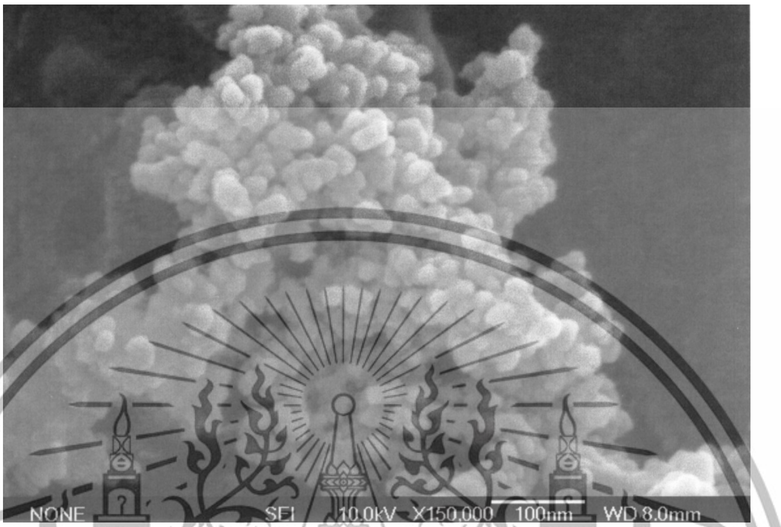

Figure 25 SEM microscope reference

4.1.3. Viscosity of flame retardant

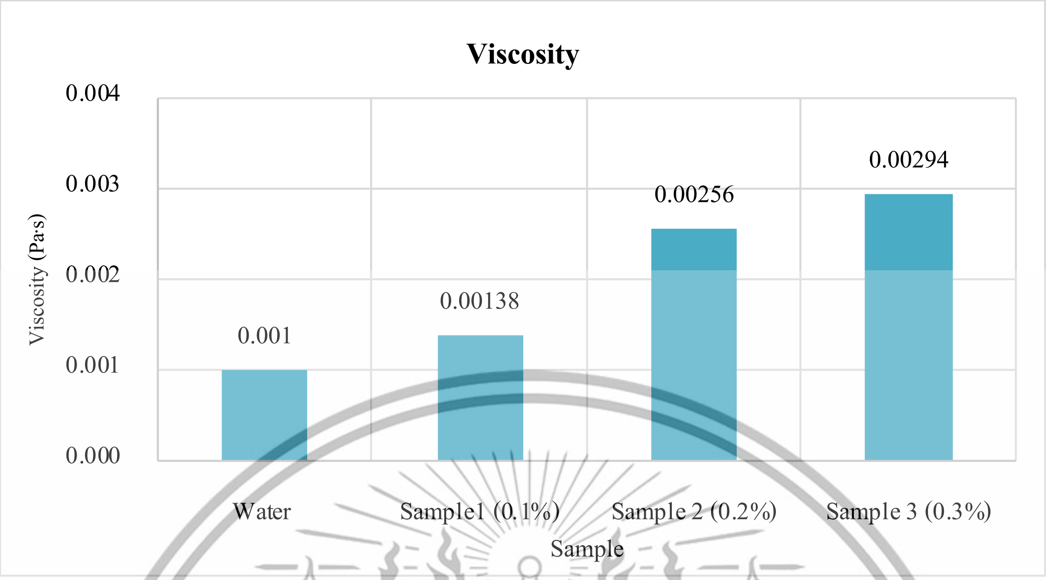

Figure 26 viscosity of the sample

In coating application, the viscosity of liquid can determine the flow properties, coverage, and adhesion. The resistance of a fluid to flowing or deforming below an applied tension is measured by its viscosity. The viscosity of the coating substance will have an effect on how it spreads, adheres, and dries on the surface when coating vegetation.

Comparison of high and low viscosity for coating, high viscosity has been demonstrated to provide higher coverage and adhesion to the substance because it tends to produce a thicker layer on the substrate, increasing the coating's overall durability and protective properties. Due to a higher fluid viscosity, high viscosity may cause a decrease in spray ability or ease of application. This might make it difficult to provide uniform coating, particularly when using spraying. For low viscosity, it is easier to apply as flow more freely which can result in more uniform coverage with less effort and may not adhere as well to the vegetation especially on vertical surface. Low viscosity can dry faster than high viscosity, as thinner films tend to evaporate solvents but may not provide the same as high viscosity.

All samples are much more viscous than water when compared to all other samples. As a result of spraying, we decided on using the same amount of guar gum as sample 2. Because we must test each sample's spray ability using a full cone nozzle spray at the same pressure, we cannot use guar gum concentrations higher than 0.2%. When using nearly as much guar gum as sample 3, we cannot perform the full cone pattern, and it will influence coating. The result of sample 3 was not a full cone pattern however, its pattern is a flat fan and is relatively straight.

4.1.4. Surface tension

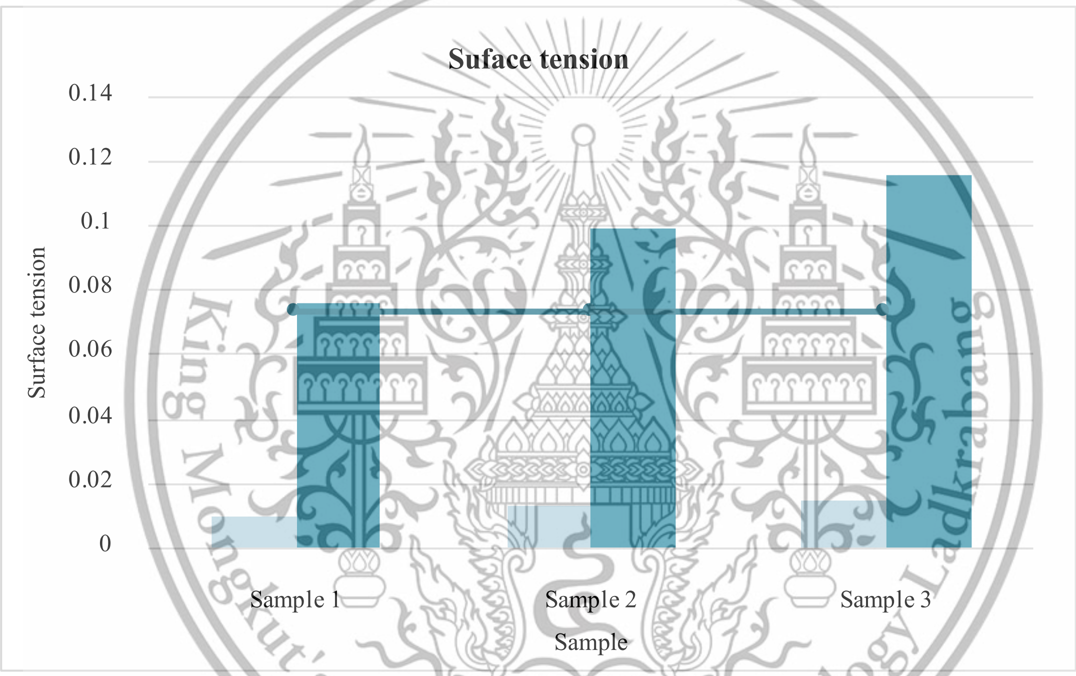

Figure 27 Surface tension at different concentration of guar gum

Surface tension is the property of liquids that arises due to the cohesive between liquid at the surface of vegetation. Adhesion is another factor to consider, low surface tension tends to have better adhesion as improved wetting and spreading properties that allow them contact with vegetation which have stronger bond to help withstand rain and wind. For spreading lower surface tension will spread more easily and cover a large area.

When we compare the surface tension of the sample compared with water, we can conclude that sample 1 has a surface tension that is slightly higher than water. It might indicate that it has water-like wetting and spreading behavior. Sample 2 is higher than both sample 1 and water. As compared to water and sample 1, sample 2 might have lesser wetting and spreading properties, as can be observed. Although sample 3 has the highest surface tension of the three, its wetting and spreading capabilities may be lowered more than those of the other two samples, which may indicate that sample 3 has less effective adhesion and coverage on vegetation.

Based on the surface tension, sample 1 is the most suitable choice for coating on vegetation among three samples. However, it must consider other factors such as viscosity and desired coating performance. But when sample 1 is close to water that means when we spray the liquid will fall from normally it should adhesion on vegetation.

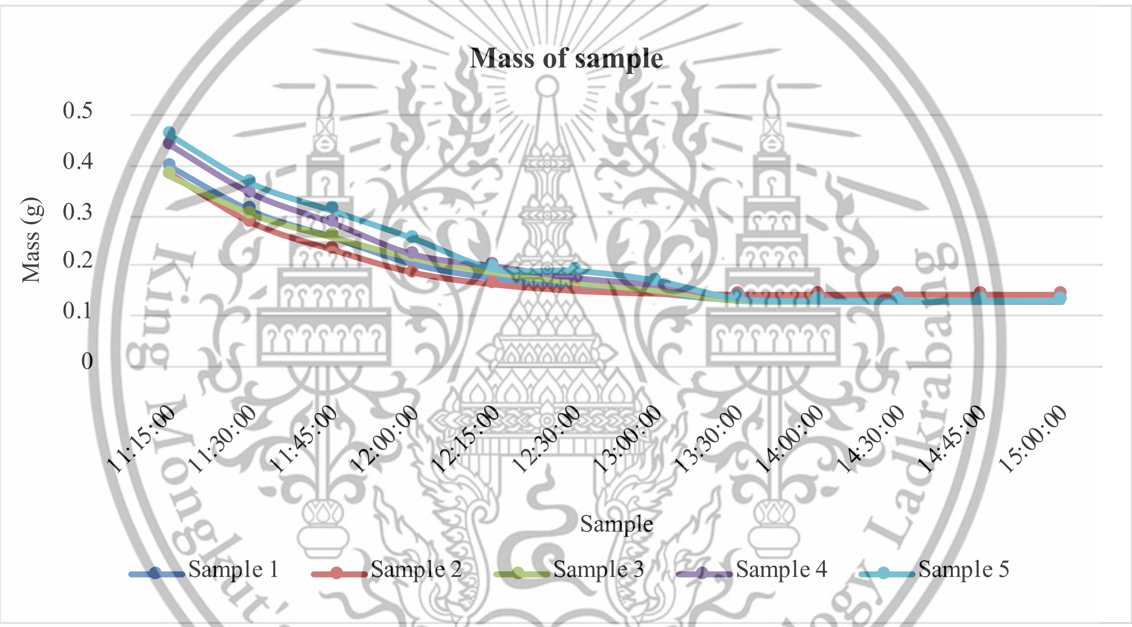

Figure 28 Graph of time until flame retardant dried

4.1.5. Time until dry

Long-term flame retardants are designed to prevent a flame from spreading for a long time, even after the water component has evaporated. Our flame retardant is used in the prevention of forest fires and control of wildfires. The primary component, such as diammonium phosphate, releases water to create a barrier. The next component is a gelling agent, which helps the flame retardant thicken and adhere to surfaces, particularly vertical surfaces, more effectively.

The flame retardant is sprayed onto the surface. A coating of retardant chemical will remain after the water component of the flame retardant evaporates. This layer provides long-term flame resistance. According to our results, under conditions of typical air temperature, pressure, humidity, and wind speed, the evaporation process of water occurs over the duration of around two hours after the application of a flame retardant. We can make sure that there is continuous fire protection, even if water has evaporated.

The evaporation time can influence the flame-retardant performance by affecting the formation of protection layer on vegetation surface. If the flame retardant evaporates too quickly it may not have sufficient time to form the layer.

4.2. Lab scale test

4.2.1. Mass residue

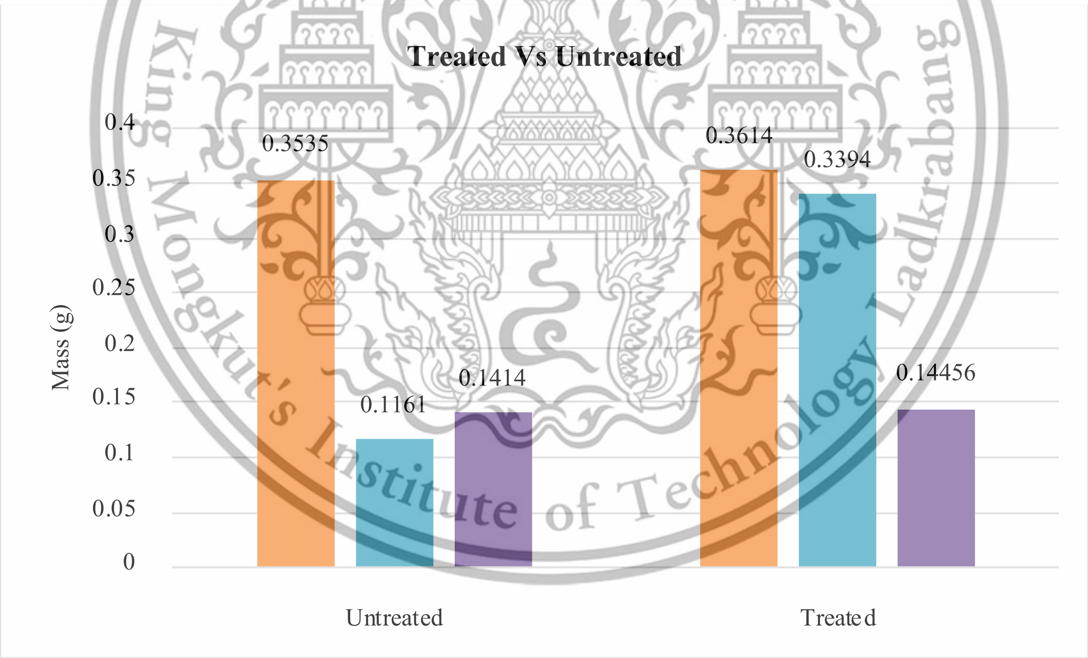

Figure 29 graph compare mass loss between treated and untreaded.

From testing, the mass residue of treated and untreaded sample on square pine wood box was evaluated by comparing the mass loss for each sample after 30 second exposure to fire. Mass loss of untreated sample is 67.2% which exceeds the standard which is 40%. On the other hand, the treated sample that coating with flame retardant solution that included sodium silicate, phosphoric acid, DAP (diammonium phosphate), magnesium hydroxide, and aluminum hydroxide, and result of treated sample has mass loss of 6.1%, which was well below the 40% requirement. This explains how the flame-retardant solution works to increase the treated pine wood's fire resistance.

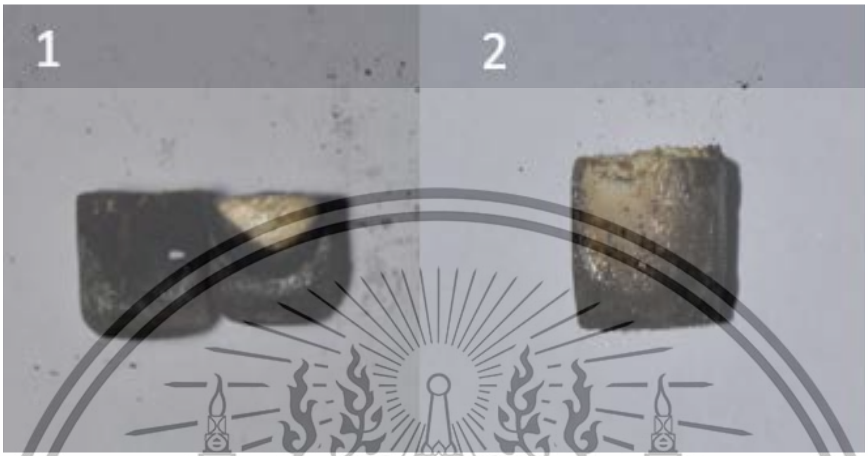

Figure 30 Comparison of treated and untreaded after burned.

The flame-retardant systems work by increasing endothermic reactions and dehydration, reducing the availability of flammable gases, and producing protective layers on the material surface that serve as barriers to prevent flammability. The addition of magnesium hydroxide and aluminum hydroxide boosts the performance of the flame retardant by increasing endothermic decomposition and producing water vapor, which cools the surroundings and dilutes combustible gases, making it harder for the fire to spread.

4.2.2. Burning test (Different height)

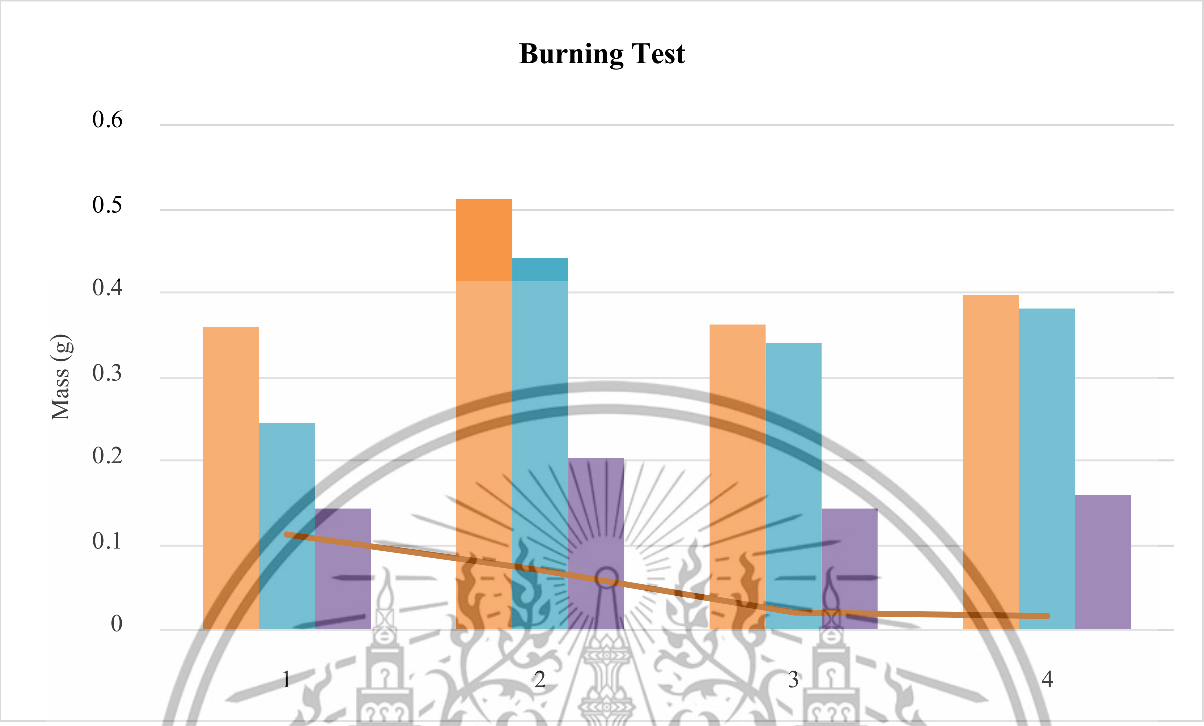

Figure 31 Graph of burning test.

From testing that vary on height, on samples of pine wood exposed to flames at different distances, the efficacy of a flame-retardant treatment containing sodium silicate, phosphoric acid, DAP, magnesium hydroxide, and aluminum hydroxide was examined. The flame-retardant efficiency under various fire exposure conditions was emphasized by the treated samples reduced mass loss as the distance from the flame increased. By encouraging endothermic processes, dehydration, and the formation of protective layers on the surface of the material, the flame retardant prevents flame spread and improves fire resistance. All evaluated samples showed mass loss significantly below the 40% limit, demonstrating that the flame-retardant solution provides sufficient fire protection at varying distances from the flame.

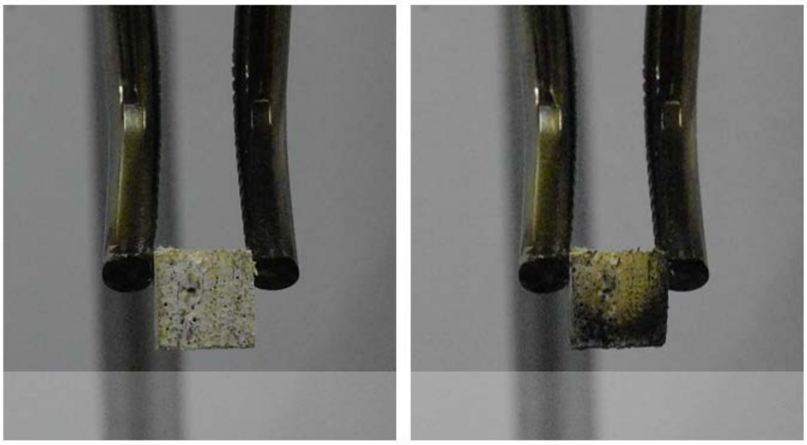

Figure 32 Before and after burning test.

In conclusion, the tests performed on samples of treated and untreated pine wood show that the fire resistance can be improved by applying a flame-retardant treatment that includes sodium silicate, phosphoric acid, DAP, magnesium hydroxide, and aluminum hydroxide. The untreated sample showed mass loss that was higher than the 40% limit, which indicated low fire resistance. The treated samples, on the other hand, consistently showed reduced mass loss when exposed to flames at different distances, which was well within the 40% requirement, showing the effectiveness of the flame-retardant solution.

4.2.3. Burning test (second solution)

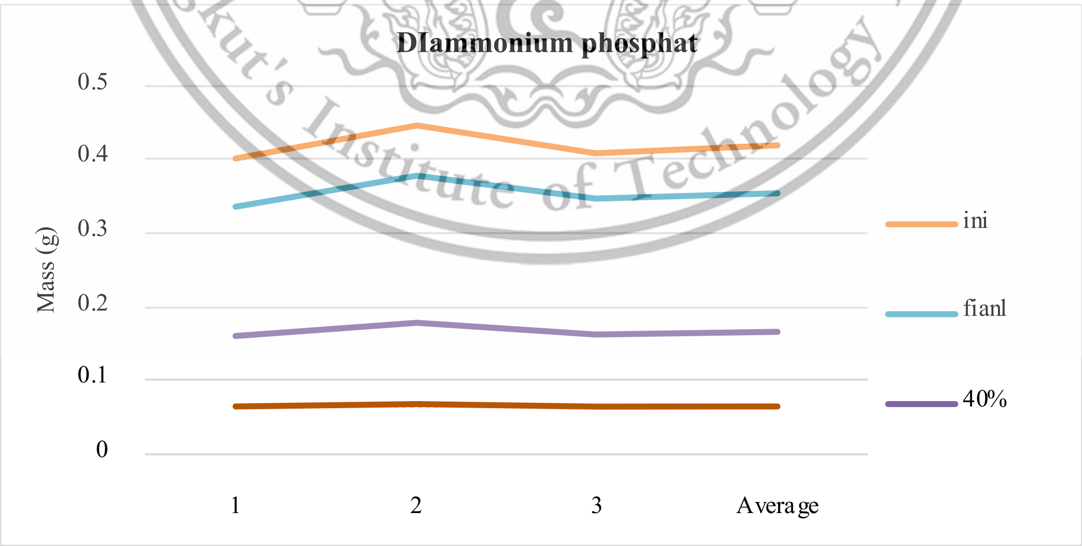

Figure 33 The result of DAP solution weight loss test.

The consistent weight loss observed across the three pine wood samples that were coated with the flame retardant, despite their different initial masses, suggests a robust efficacy of the flame retardant. This indicates that the flame-retardant solution consistently reduces the combustibility of the pine wood, leading to a similar percentage of weight loss during testing, regardless of the initial mass of the sample. This uniformity in results is promising as it demonstrates that the flame retardant's performance is not significantly influenced by the size or mass of the wood it is applied to. Instead, it consistently protects against fire damage across different samples.

4.2.4. One month test

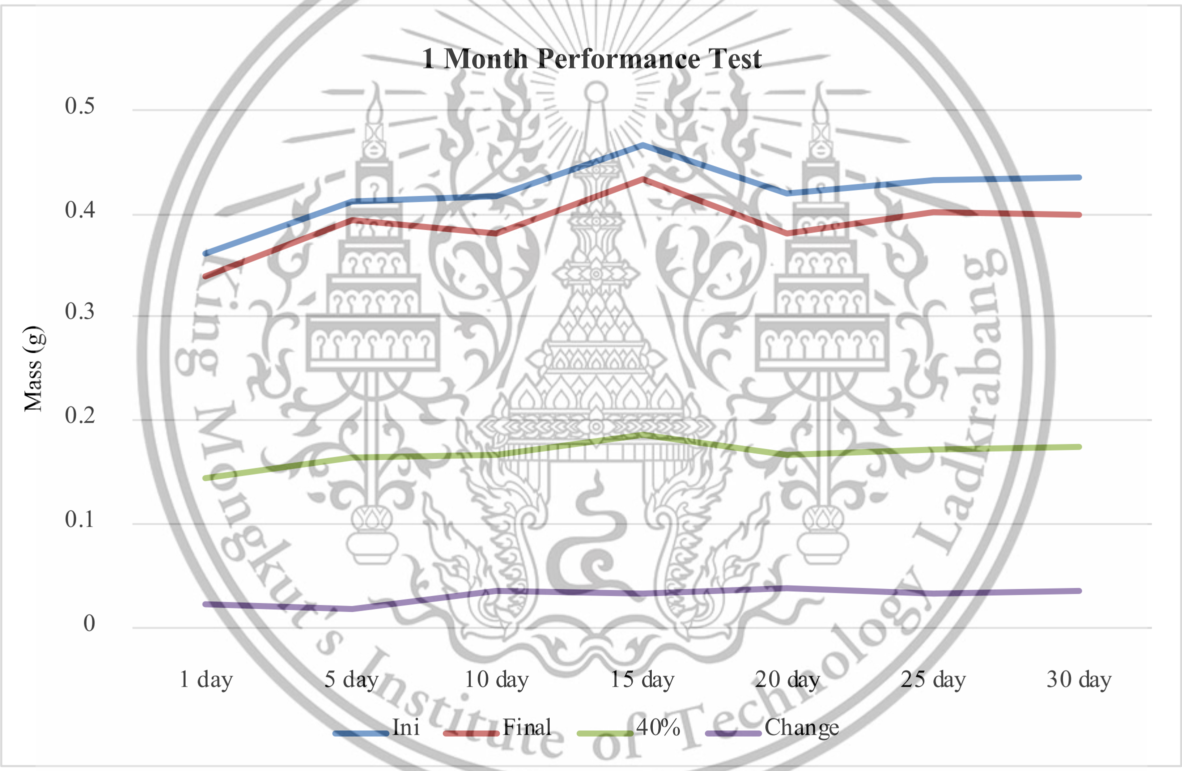

Figure 34 Result of weight loss of 1 month performance test.

The flame retardant-coated samples performed a one-month performance test, and the results reveal that the weight loss is largely stable over time, increasing just slightly after five days from the initial test. The steady weight loss of the flame-retardant coating, the effects of the environment, or the aging process on the material flame resistance might all contribute to this small increase in weight loss over time. It implies that although the flame-retardant coating largely maintains its efficacy, there can be a modest decline in its performance over time.

The consistency of the results over the course of the month suggests that the flame retardant has an acceptable amount of durability. The small increase in weight loss over time, however, suggests that there could be space for advancement in the design or application of the coating to improve its durability.

4.2.5. Burning time

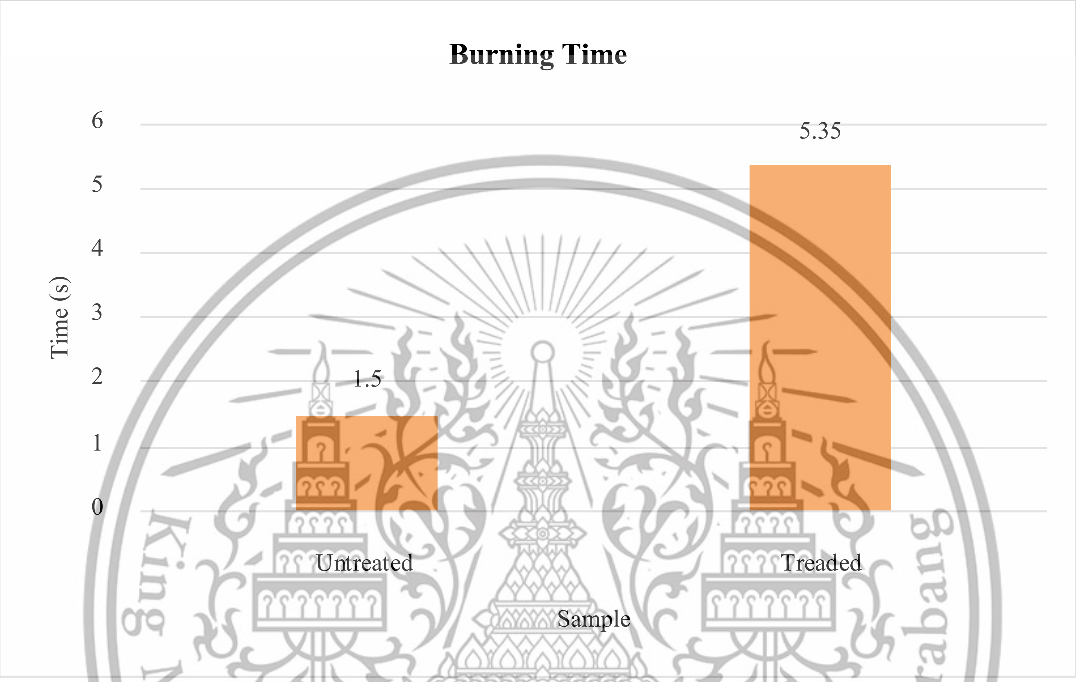

Figure 35 Burning time of sample.

The time test result for treated and untreated pine wood samples that exposed to fire. The untreated sample ignites and completely burns away in just 1 minute 50 seconds. In contrast, the treated sample which coat with flame retardant containing sodium silicate, phosphoric acid, diammonium phosphate, magnesium hydroxide and aluminum hydroxide can be able to withstand the fire exposure for 5 minutes 35 seconds without igniting. This results in a char appearance being consumed by fire. These can be concluded that it can enhance fire resistance by using the flame retardant effectively reduce the risk of fire damage.

Figure 36 Before and after burning test.

4.2.6. Ignition test

A more detailed analysis of ignition time shows the importance that flame retardant treatments make to improving material fire resistance. The untreated pine wood sample started a fire after only five seconds of being in contact with the flame, indicating its extreme combustibility and lack of inborn fire resistance. Its quick ignition period presents an important concern for an incidental fire potential to spread quickly and cause significant damage.

Figure 37 Ignition test of treated and untreaded

However, the treated sample, which had a coating of flame retardants including sodium silicate, phosphoric acid, DAP, magnesium hydroxide, and aluminum hydroxide, was capable of withstanding fire exposure for 5 minutes and 35 second without igniting. This delayed ignition period is evidence of the way the flame-retardant treatment works to prevent or stop the start of combustion. By encouraging endothermic reactions, dehydration, and the formation of protective layers on the surface of the material, the flame retardant efficiently prevents flame spread and lowers flammability.

The significant difference in ignition time between the treated and untreated samples emphasizes how important it is to give materials like pine wood flame retardant treatments to increase fire resistance. These treatments can reduce the chances of fire damage, restrict the potential of fire spread, and buy crucial period for control and evacuation operations by delaying or avoiding ignition.

4.2.7. Grass test

Figure 38 Burning test in laboratory scale.

The grass burn test results allow us to make the conclusion that the flame-retardant treatment has been effective in enhancing fire resistance and preventing the spread of fire in treated areas. The treated side of the grass did not burn when exposed to fire while the untreated side was entirely burned when the flame retardant was sprayed to half of the grass and the other half was left untreated. This result shows the effectiveness of the flame-retardant treatment in preventing ignition and combustion in the treated grass.

The composition of the flame retardant, which may contain components like sodium silicate, phosphoric acid, DAP, magnesium hydroxide, and aluminum hydroxide, is responsible for its efficiency in stopping the treated grass from burning. Together, these components enhance endothermic reactions, dehydration, and the development of protective layers on the surface of the material, thereby preventing flame spread and lowering flammability. On the other hand, the second flame retardant, which uses magnesium hydroxide as its main component, displayed a slightly lower level of fire resistance.

Although the treated grass did burn, the extent of the burning was minimal compared to the untreated grass. This suggests that the second flame retardant still provides some level of fire resistance, but it may not be as robust as the first flame retardant.

4.3. Pilot scale test

4.3.1. Height of flame

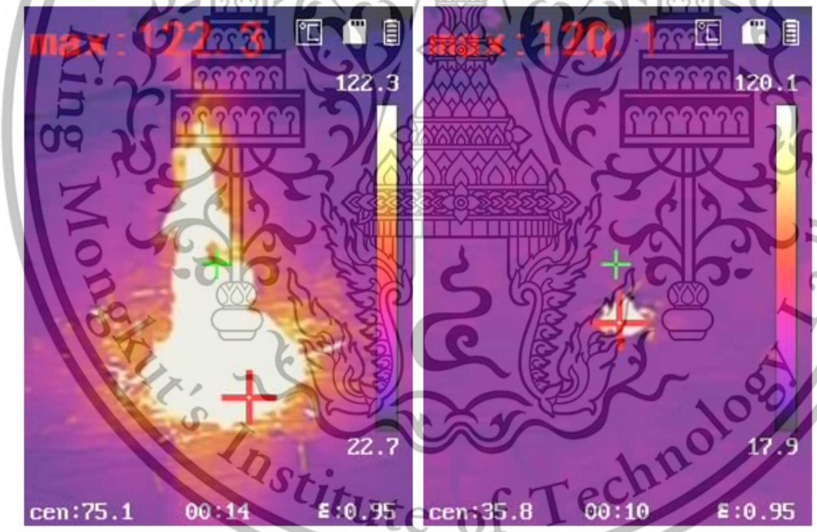

Figure 39 Height of flame.

Despite using the same fuel, there is a reduction in flame height when using the flame retardant, which suggests that the flame retardant is successfully reducing the amount of flammable gases released by the fuel. This shows that either the flame retardant is cooling the fuel, slowing the pace at which it decomposes into flammable gases, or it is establishing a barrier that prevents the fuel from encountering oxygen, which is required for burning.

The amount and temperature of flammable gases emitted from the fuel during a fire essentially impacts the height of the flame. The fuel is thought to be burning less efficiently if the flame height is lower this could be because combustible gases are releasing more slowly or are burning at a lower temperature. Because the fire may spread more slowly and might be simpler to put out, the lower burning intensity is good for fire safety.

4.3.2. Rate of flame spread

The rate of flame spread is how quickly it burns through grass or other combustible materials. The type of fuel and moisture content of the fuel, the weather, and the geography all have an impact on this rate. Warmer temperatures, lower humidity, wind, more dense, drier fuels, and other factors can all increase the start of a fire. Additionally, preheating and the effects of the topography on the availability of fuel contribute to flames spreading more quickly upwards. Understanding these variables is essential for successful planning of resources, risk assessment, and fire behavior prediction. To assess flame spread rates and other fire characteristics and to aid decision-making during wildfire incidents, fire behavior models and simulations are frequently utilized.

When comparing the rate of flame spread between normal grass at 3.5 m/min and treated grass at 0.3 m/min under the same conditions of wind speed (22 km/hr) and temperature (34°C), there is a significant difference in fire behavior between the two types of grass. A common area of grass has a flame spread rate of 3.5 m/min, which makes it highly combustible and allows rapid fire to spread, especially when the weather is favorable for wind-driven fire spread and quick drying. Normal grass is more at risk of wildfires and increases the risk of damage to surrounding areas due to its excellent fuel structure and continuity, which also contribute to the rapid rate of flame spread. The combustibility and ignition resistance of treated grass, which has a flame spread rate of 0.3 m/min, have been decreased by using flame retardant transformation. Even in the same difficult weather conditions, treated grass has a slower rate of flame spreading, indicating that it is less likely to spread a fire quickly. The slower rate of flame spread in treated grass gives firefighters more time to put out flames and could contribute to reducing the amount of damage caused by wildfires.

In summary, normal grass with a flame spread rate of 3.5 m/min is significantly more susceptible to rapid fire spread compared to treated grass with a flame spread rate of 0.3 m/min. The treated grass provides improved fire resistance, reducing the risk of wildfires and allowing more time for fire suppression actions.

4.3.3. Area of burning

The results of the grass burn test for 4 different flame-retardant formulations show the impact of different sodium silicate ($Na2SiO3$) concentrations on the treated grass ability to withstand fire. Different amounts of $Na2SiO3$ were added to each formulation, which began with a mixture of water and a 10% DAP solution to make a 1-liter solution.

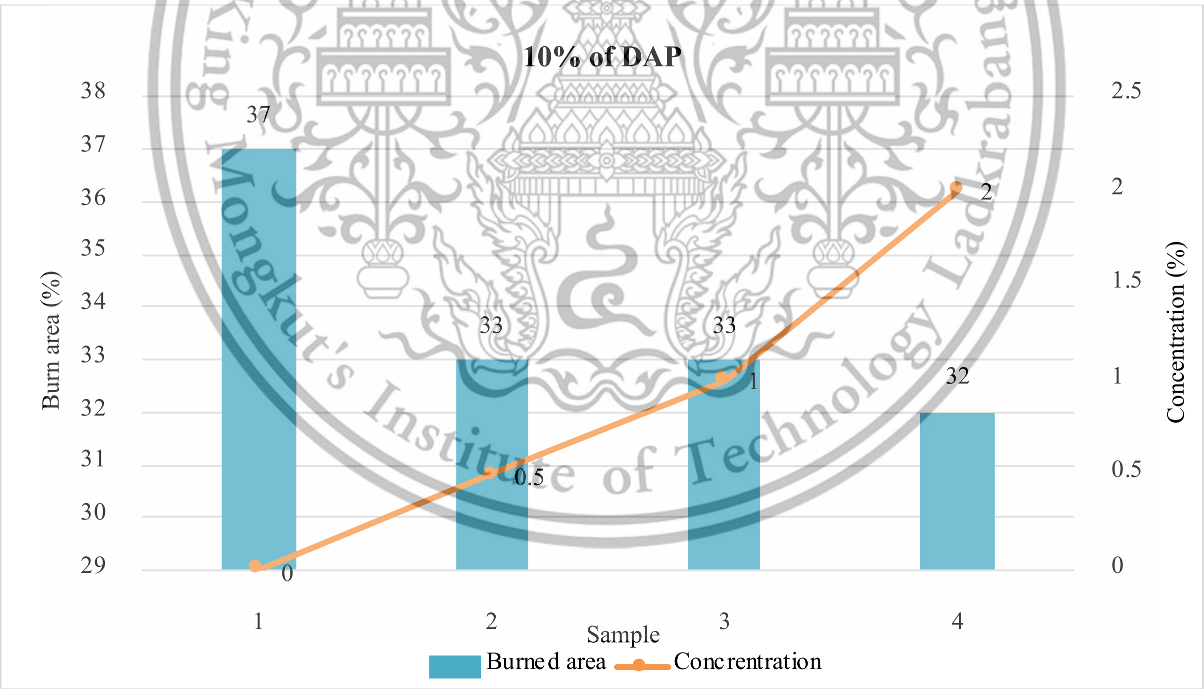

Figure 40 Graph of area burned with 10% DAP solution

The results presented show that the addition of sodium silicate to the DAP solution improves fire resistance slightly as indicated by a reduction in the percentage of area burned. With the addition of just 0.5% Na2SiO3, the area burned decreased from 37% in Sample 1 to 33% in Sample 2, showing that even small levels of sodium silicate can help enhance fire resistance.

However, the increase in fire resistance is quite small, with the area burned only dropping from 33% to 32% when the concentration of Na2SiO3 rises from 0.5% to 2%. This might mean that if sodium silicate concentrations are increased past a certain threshold, their efficacy starts to decline.

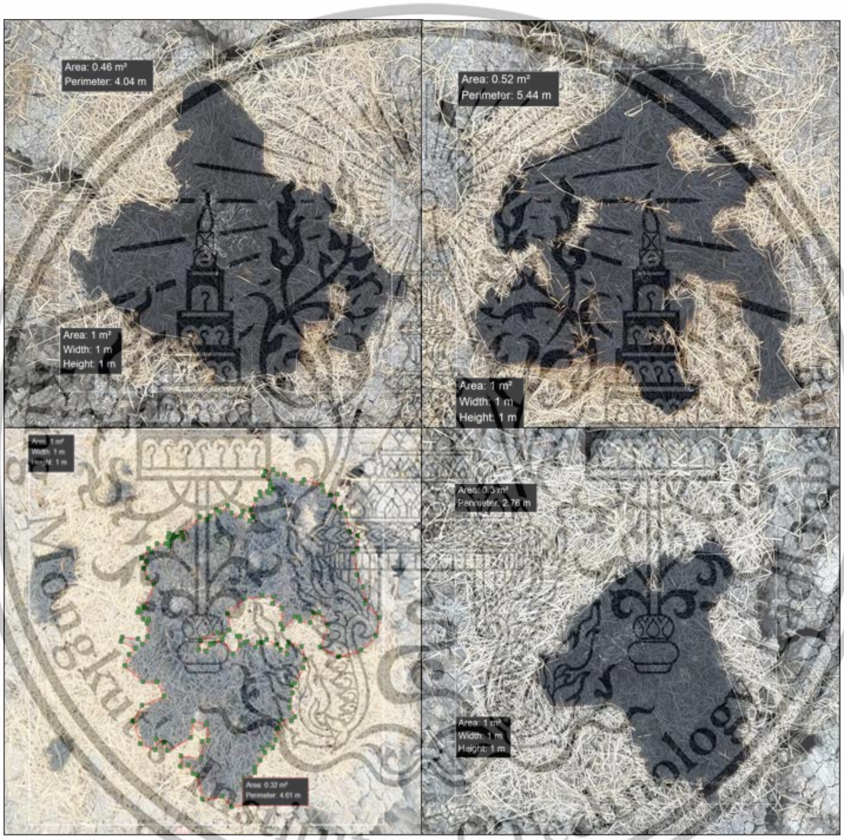

Figure 41 Result of Grass burned

4.3.4. DAP 13.5% with different Sodium silicate concentrations

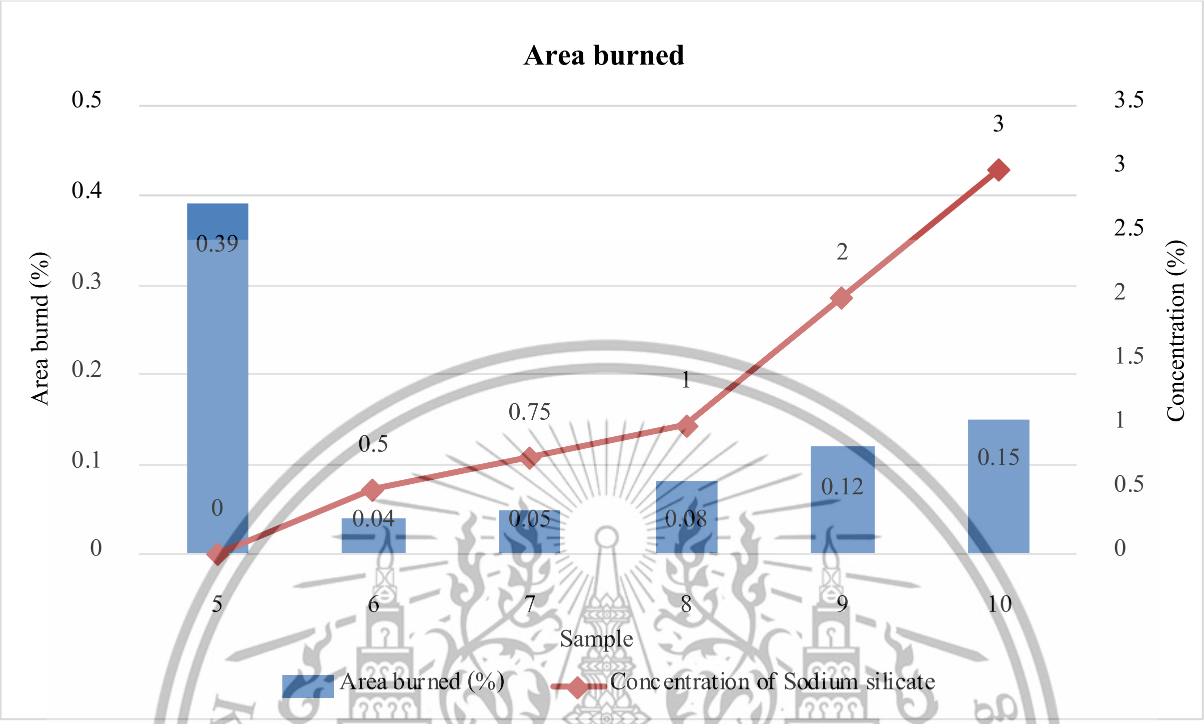

Figure 42 Graph of area burned for 13.5% of DAP

The results of differed sodium silicate (Na2SiO3) concentrations on the fire resistance of the treated grass when combined with a 13.5% DAP solution are shown in the results of 6 different flame-retardant formulations grass burn tests. Different amounts of Na2SiO3 were added to the formulations, which were produced by combining a 13.5% DAP solution with water to make a 1-liter solution.

The results obtained show that the addition of sodium silicate considerably increases the fire resistance, shown from a significant reduction in the area burned when comparing Sample 1 (DAP only) with Sample 2 (DAP along with Na2SiO3). But when the Na2SiO3 concentration rises over 0.5%, the area burned additionally increases, showing a reduction in fire resistance.

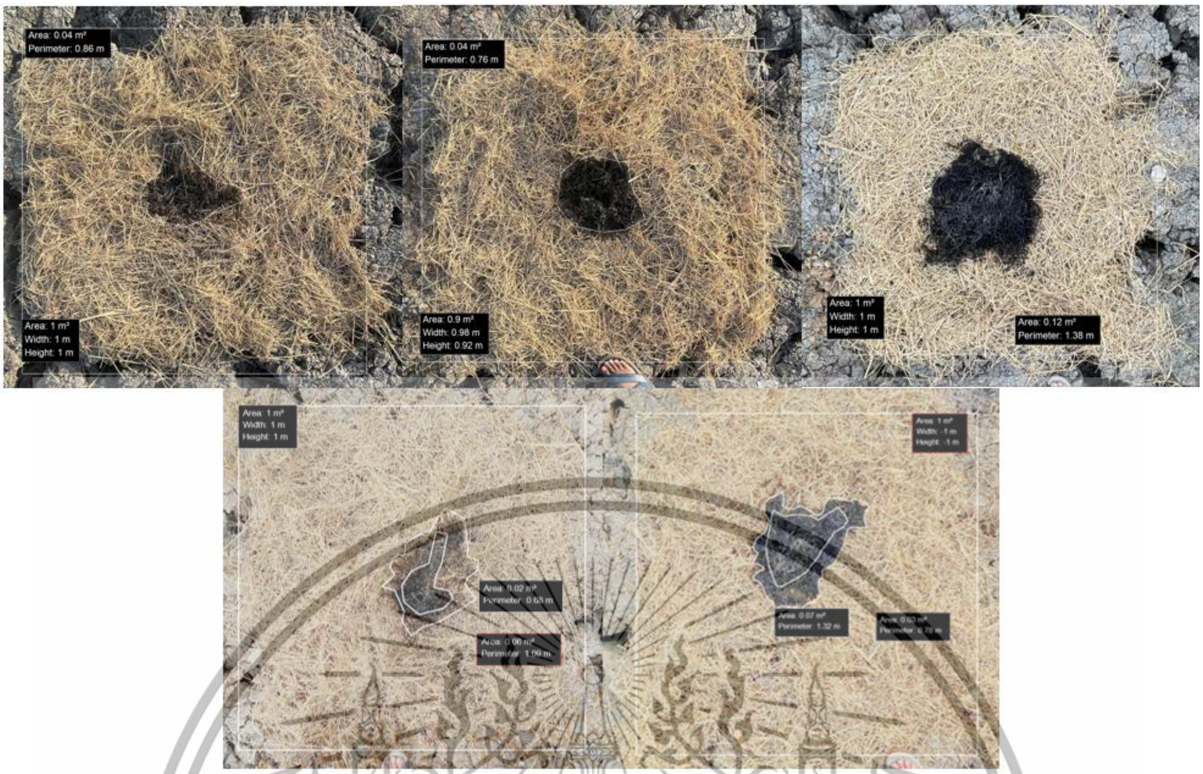

Figure 43 Result of grass burned

This trend shows that while adding sodium silicate to DAP can increase fire resistance, there is an appropriate range of sodium silicate concentrations that should be used to achieve the highest level of fire resistance. The flame-retardant performance can decrease after this point. Additionally, the earlier discovery of gel formation at concentrations above 1% may be related to the increase in the area burned at higher Na2SiO3 concentrations. The characteristics and application of the flame retardant may be impacted by gel-like consistency, thereby lowering its effectiveness.

4.3.5. DAP 13.5% with magnesium hydroxide

The results of four different flame-retardant formulations grass burn tests show the combined effects of magnesium hydroxide (Mg(OH)2) and sodium silicate (Na2SiO3) on the treated grass capability to withstand fire when added to a 13.5% DAP solution. Each formulation was produced by combining a 13.5% DAP solution with water to obtain a 1-liter solution, and then adding different amounts of Na2SiO3 and Mg(OH)2.

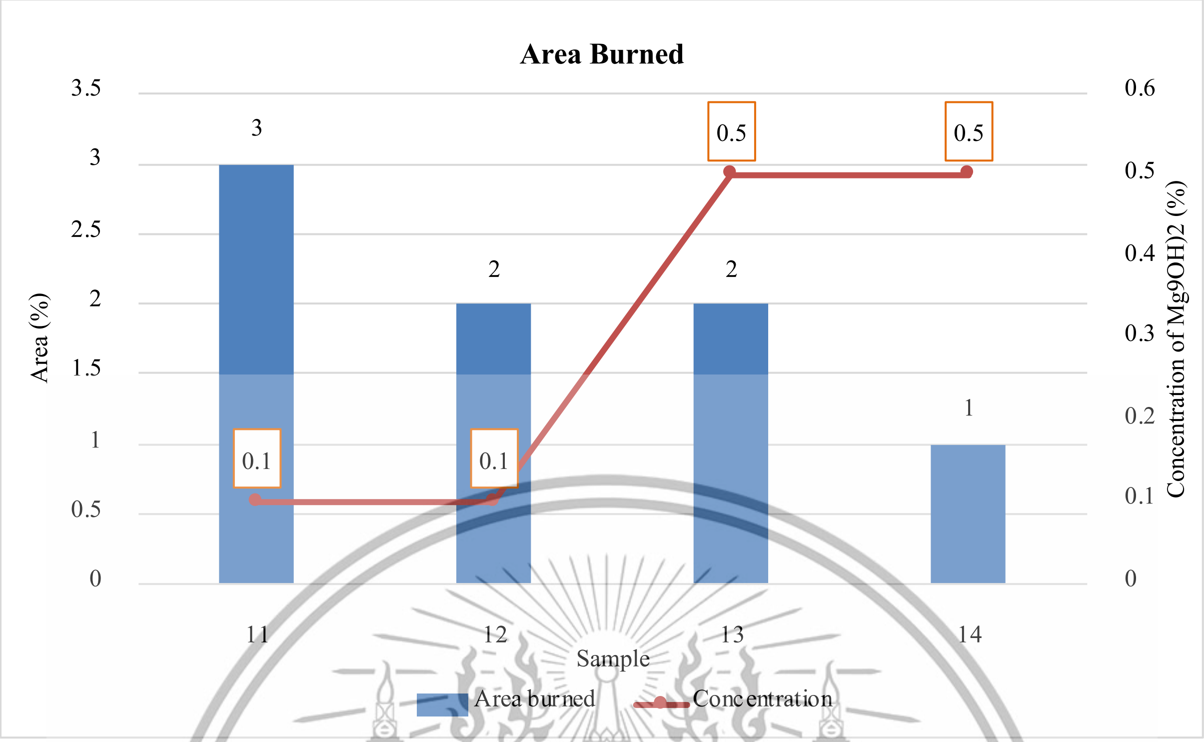

Figure 44 Graph of area burned with adding magnesium hydroxide

The least amount of burning was observed in Sample 4, which had the greatest concentrations of both Na2SiO3 and Mg(OH)2, showing the significant improvement in fire resistance of the treated grass that occurs from the addition of Mg(OH)2 to the flame-retardant formulation. According to the recent trend, sodium silicate, magnesium hydroxide, and DAP can be combined to provide an effective flame-retardant formulation, with Mg(OH)2 potentially enhancing the fire resistance provided by DAP and Na2SiO3. Each of these elements appears to complement the others in a way that increases the compound's overall fire resistance.

4.3.6. Wind speed

The flame spread tests performed at different wind speeds provide vital information on the performance of the flame retardant and the significant impact of wind speed on flame spread. A 25 m^2 grass fill was used for these testing, with half coating the flame-retardant treatment and the remaining half going untreated.

Figure 45 Result of wind speed test

Flame retardants work by forming a shield that reduces the fuel source, in this case grass the capacity to catch fire. The protective layer has several functions. It can shield the fuel from heat and oxygen, slowing the rate of combustion it can dilute flammable gases produced during combustion, slowing the burning process even more and it can start endothermic reactions that absorb heat, cooling the fuel and containing the fire. This combination of diammonium phosphate (DAP), sodium silicate (Na2SiO3), and magnesium hydroxide (Mg(OH)2) is a flame retardant, and the processes that uses are a result of the flame retardant specific chemical composition.

In the tests, a wind speed of 9 km/hr caused a flame spread rate of 0.2 m/min and an area burned of 11.67%. In comparison to a usual flame spread rate of 3 m/min for untreated grass under comparable conditions, these values show a significant reduction. The reduction in the rate of flame spread and burned area is evidence of the flame-retardant performance. Through slowing down combustion and reducing the amount of fuel available for the fire, the protective layer created by the flame-retardant solution eventually restricts the fire's ability to spread. The area burned increased to 19.3% and the rate of flame spread doubled to 0.4 m/min when the wind speed increased to 25 km/hr. Under conditions of higher wind speed, the rate of flame spread and the area that burned increased, indicating the flame retardant's efficiency was reaching its maximum. The wind can bring heat, embers, or flames to places that haven't yet ignited, accelerating the development of the fire. Additionally, it provides more oxygen, which could ignite the fire. So, even if the flame-retardant works, its effectiveness can be affected by outside factors like wind speed.

As a result, even if the flame-retardant solution is shown to be successful in slowing the rate of flame spread and decreasing the area burned, its performance can be affected by wind speed and other environmental factors. This emphasizes the necessity of an all-encompassing fire prevention plan that includes methods for controlling environmental elements like wind in addition to an efficient flame retardant. It also emphasizes the need of continual analysis and testing to enhance flame retardant compositions and comprehend their functionality in various scenarios.

4.4. Price

Table 9 summarizes the price of flame-retardant compositions.

Name	**Amount**	**Price**	**Old solution**	**New solution**
HCl	600 ml	180	25.3	25.3
RH	1 kg	40	40	40
Ethanol	500 ml	170	12.2	12.2
DAP	1 kg	-	-	30
Ammonium Hydroxide	7 ml	1.48	1.48	-
Aluminum/Magnesium Hydroxide	135 g	216	216	-
Guar gum	5 g	3	3	3
Silica	30g	5.37	5.37	5.37
Price / L	1 L	615.85	303.35	115.87

The cost of flame-retardant solutions is significantly influenced by the price of the raw materials used in their formulation. The second solution uses a less expensive main chemical than the first solution, it is reasonable that its cost per liter would be lower. The development and use of flame retardants must take into consideration their cost-effectiveness, especially in large-scale industries like forestry or construction. It is important to remember that the flame retardant's efficacy and safety should not be sacrificed to save costs. Even if the less expensive option could seem more enticing from an economic standpoint, it is crucial to determine whether it also complies with performance requirements, is secure for intended usage, and is environmentally friendly. To guarantee that the less priced option offers an efficient and sustainable approach to fire protection, more testing and analysis may be required.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

To enhance the performance of this flame-retardant project, several considerations should be considered. Firstly, efficiency enhancement should be prioritized, focusing on improving the flame retardant's suppression capabilities while using smaller quantities. Secondly, longevity of the retardant's effectiveness post-application, including its resistance to weather conditions, needs to be addressed.

Thirdly, the ongoing commitment to safety and minimal environmental impact must be maintained. Fourthly, expanding the application to protect a wider range of materials, such as various types of woods and fabrics, could open new market possibilities. Fifthly, refining the product's ease of application, potentially through adjustments in viscosity or creating a ready-to-use variant, could increase user-friendliness. Lastly, exploring cost-effective production methods without sacrificing performance would enhance competitiveness. Thorough testing and data analysis are crucial in validating these performance improvements.

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APPENDIX

Table 10 Solution of flame retardant

Sample	DAP (%)	Na_2SiO_3 (%)	Salt (%)	Guar gum (%)
1	10	-	-	0.2
2	10	0.5	-	0.2
3	10	1	-	0.2
4	10	2	-	0.2
5	13.5	-	-	0.2
6	13.5	0.5	-	0.2
7	13.5	0.75	-	0.2
8	13.5	1	-	0.2
9	13.5	2	-	0.2
10	13.5	3	-	0.2
11	13.5	0.5	0.1	0.2
12	13.5	0.5	0.5	0.2
13	13.5	0.75	0.1	0.2
14	13.5	0.75	0.5	0.2

Table 11 Result of surface tension

	Water	**Sample 1**	**Sample 2**	**Sample 3**
Height (m)	0.01	0.015	0.013	0.01
Density (kg/m3)	1000	1050.666667	1042.333333	1037.533333
S (N/m)	0.0735	0.115836	0.09959495	0.0762587

Table 12 Result of burning test (Pine wood)

Sample	**1**	**2**	**3**	**Average**
Initial	0.4017	0.4466	0.4103	0.41953333
Final	0.3362	0.3784	0.3455	0.35336667
40%	0.16068	0.17864	0.16412	0.16781333
change	0.0655	0.0682	0.0648	0.06616667

Table 13 Flow rate of sprayer

Flow rate	**Time (s)**	**ml**	**ml/s**	**ml/hr**
1	25	835	33.4	120.24
2	25	825	33	118.8
3	25	840	33.6	120.96
4	25	837	33.48	120.528
average		33.37	120.132	

Table 14 Result of burning test (Height)

Sample	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**
Initial	0.3596	0.5124	0.3614	0.3976
Final	0.2461	0.4412	0.3394	0.381
Standard (40%)	0.14384	0.20496	0.14456	0.15904
Change	0.1135	0.0712	0.022	0.0166

Table 15 Result of 1 month performance

Sample	1	2	3	4	5	6	7
	1 day	5 days	10 days	15 days	20 days	25 days	30 days
Initial	0.3614	0.4111	0.4163	0.4662	0.4183	0.4325	0.436
Final	0.3394	0.3929	0.38	0.4333	0.38	0.4004	0.4
40%	0.14456	0.16444	0.16652	0.18648	0.16732	0.173	0.1744
Change	0.022	0.0182	0.0363	0.0329	0.0383	0.0321	0.036
%Change	6.08743774	4.42714668	8.719673313	7.05705706	9.15610806	7.42196532	8.25688073

Table 16 Result of treated and untreated sample

Sample	Untreated	Treated
Initial	0.3535	0.3614
Final	0.1161	0.3394
Standard	0.1414	0.14456
Change	0.2374	0.022
Time	1.5	5.35

Table 17 Viscosity of each sample

Viscosity (cP)						Avg
Sample1	0.387	0.387	0.387	0.400	0.387	0.389
Sample 2	0.213	0.287	0.200	0.187	0.367	0.251
Sample 3	0.333	0.333	0.367	0.200	0.200	0.287

Table 18 Purity of silicon dioxide

		Untreated		Treated	
No.	**Component**	**Commercial g.**	**Lab g.**	**Commercial g.**	**Lab g.**
1	SiO3	98.7	98.9	99.4	99.7

Table 19 Grass burned test

Sample	Area	Total A (m^2)	Burned A	%
1	1*1	1	0.37	37
2	1*1	1	0.33	33
3	1*1	1	0.33	33
4	1*1	1	0.32	32
5	1*1	1	0.39	39
7	1*1	1	0.05	5
8	1*1	1	0.08	8
9	1*1	1	0.12	4
10	1*1	1	0.15	4
11	1*1	1	0.03	3
12	1*1	1	0.02	2
13	1*1	1	0.02	2
14	1*1	1	0.01	1

Table 20 Composition of silicaon dioxide

		Untreated		Treated	
No.	**Component**	**Commercial g.**	**Lab g.**	**Commercial g.**	**Lab g.**
1	Fe2O3	0.0618	0.0413	0.0275	0.0193
2	Al2O3	0.904	0.643	0.274	0.0761
3	SiO3	98.7	98.9	99.4	99.7
4	P2O5	0.0533	0.0269	0.0721	0.0063
5	SO3	0.0275	0.0501	0.0441	0.051

Table 21 Evaporation rate test

	11:15:00	11:30:00	11:45:00	12:00:00	12:15:00	12:30:00	13:00:00	13:30:00	14:00:00	14:30:00	14:45:00	15:00:00
Sample 1	0.3965	0.3089	0.2567	0.2034	0.1749	0.1573	0.1454	0.1319	0.1315	0.131	0.131	0.131
Sample 2	0.3822	0.2858	0.232	0.1865	0.1632	0.1506	0.145	0.143	0.1427	0.1434	0.1429	0.1428
Sample 3	0.3773	0.3023	0.2567	0.2152	0.1868	0.1665	0.1512	0.1308	0.129	0.129	0.1291	0.1289
Sample 4	0.4393	0.3437	0.285	0.2225	0.1992	0.1759	0.1616	0.136	0.13	0.1291	0.129	0.1289
Sample 5	0.4586	0.3637	0.3091	0.2542	0.1937	0.1902	0.1705	0.1345	0.1303	0.1303	0.1301	0.1303