Inorganic flame retardants’ efficacy of Aluminum Hydroxide, Magnesium Hydroxide in the combustion rate of intermediate Calamagrostis from Ecuador’ Moorlands

M Córdova-Suárez¹, E M Barreno-Avila², D S Pozo-Álvarez³, and J C Córdova-Suárez³

¹ School of Engineering, Universidad Nacional de Chimborazo, Av. Antonio Jose de Sucre, Riobamba-Ecuador
² Faculty of Science and Engineering, WA School of Mines: Minerals, Energy and Chemical Engineering, Kent St, Bentley WA 6102, Australia
³ School of Food Science and Engineering, University, Universidad Técnica de Ambato, Los Chasquis Avenue and Río Payamino, 180201, Ecuador

E-mail: hesconsultores@hotmail.com

Abstract. In this research, intermediate calamagrostis vegetal fiber (FIC) combined samples were carried out in combination with polyester resin (RP), Aluminum Hydroxide (HA) and Magnesium Hydroxide (MH). The aim of this study is to determine inorganic flame-retardant effectiveness in the intermediate calmaragrostis’ combustion rate reduction from Ecuador’s moorlands and possible forest fires’ control of this endemic plant species. The flammability index was obtained following the ISO 3795 standard; In addition, the contamination degree: Carbon Monoxide (CO) was determined, following the standard EPA 40 CFR, method 60 Annex A. The composite material was evaluated in a horizontal flammability chamber. Furthermore, the experimental design considered seven tests, one control and two flame retardants’ types. Aluminium Hydroxide and Magnesium Hydroxide accounted for three different concentrations at 3%, 6% and 9% percent each one. Thus, these flame retardants’ effectiveness was greater for Aluminium Hydroxides at all the proposed concentrations, while for Magnesium Hydroxide; its effectiveness was positive for a concentration of 9% only. The study determines that the best combination of materials are: 70% FIC, 21% PR, 9% HA, resulting in a combustion rate of 190.98 mm / min and self-extinguishing capacity. Finally, an average decrease of 50% in the generation of CO and the amount of smoke was determined.

1. Introduction
When a fire occurs every second counts and to prevent it, or at least to slow its spread, many woods, plastics, fabrics and electronic devices are protected with fire retardants that reduce the flammability of the product by eliminating the chain reaction of a fire [1]. Depending on their nature, these compounds can act physically (by cooling, formation of a protective layer or dilution of the combustible material) or chemically (reaction in condensed or gaseous phase). Hence, they can interfere with several phenomena involved in the combustion of a polymer (heating, ignition, pyrolysis, thermal degradation, flame propagation) [2]
There are several fire retardants, inorganic ones based on halogenated compounds, phosphorus, antimony trioxide, and nitrogen; and intumescent, among others that act in different ways [3].

Halogenated Compound. The most commonly used fire retardants are those based on halogens; however, their application has been restricted due to the environmental problems they produce [4]. Halogens, mainly chlorine and bromine, are found in the chemical structure of many of the most effective and widely used flame retardant additives, such as brominated compounds [5]. These are developed by removing the H+ and OH− radicals in the gas phase of the flame. This slows down the burning process. Thus, reducing the production of heat and the generation of flammable gases [6]. On the other hand, the production of harmful and corrosive smoke and toxic gases during combustion, as well as environmental regulations and considerations, have promoted the use and development of halogen-free flame retardants [7].

Inorganic compounds (aluminum hydroxide, magnesium hydroxide). They obstruct the flame through physical processes such as the release of water or non-flammable gases that dilute those who fan the fire, cooling and producing a non-flammable and resistant layer on the surface of the material [8]. They decompose through an endothermic reaction, releasing water vapour which removes heat and reduces the formation of combustible gases, together they form a protective layer on the surface of the material which intervenes by slowing down the spread of thermal degradation [1,8].

Aluminium hydroxide and magnesium hydroxide flame retardants are considered non-toxic and therefore environmentally friendly, in addition to producing low smoke emissions [9]. Aluminum and magnesium hydroxides (M(OH)x) decompose endothermically and this begins at temperatures close to 200 °C and 300 °C respectively, releasing water in the form of vapour and thanks to this phenomenon this form of metal oxide (M2Ox) [7].

Phosphorous Base. The phosphorus base plays an efficient role in the solid phase of the materials being burned. When heated, the phosphorus reacts to give a polymeric form to phosphoric acid, forming a crystalline layer that inhibits the process of pyrolysis and release of flammable gases, which are needed to maintain the flame. By this mechanism the amount of fuel is significantly compressed because more carbonized zone is formed than fuel gas [6].
Figure 2. Processes involved in Phosphorous-based fire retardants [3]

Intumescent Coatings. Intumescent coatings are used to protect materials such as wood and plastics from flame and prevent incineration. They are also used to safeguard steel and other materials, retarding flame and structural damage during fire. They are produced from a mixture of products that are used on the surface like a paint. They are intended to disperse to form an insulating and fire-resistant layer covering the material exposed to the heat [6].

2. Materials and Methods

2.1. Raw material collection.
• For Calamagrostis Intermedia sample; the land was identified, where the sampling was done, and this was collected in the province of Chimborazo with the coordinates 1°46'23.3 "S 78°44'53.3 "W
• Aluminium hydroxide and magnesium hydroxide were collected from the laboratories of the Faculty of Food Science and Engineering and Biotechnology of the Technical University of Ambato.
• The polyester resin was obtained from the Master Fiber factory located in the city of Ambato with coordinates 1°12'43.5 "S 78°35'42.5 "W

2.2. Raw material cleaning.
• The collected sample of intermediate calamagrostis was exposed to the sun for complete drying of the fibre.
• The sample was cut to a length of 400mm without roots.
• Any remaining dust particles were removed.

2.3. Elaboration of the mold for specimens (test material).
• The mould for making the specimens (test material) was made of wood.
• The dimensions were 400 mm long by 400 mm wide, as 5 replicas were made for each concentration.
• The specimens (test material) were then removed from the mould and cut to the dimensions according to ISO 3795.

2.4. Cleaning the specimen mold (test material).
• The wooden mould was cleaned with paint thinner the first time, from the second time onwards, any resin residue was cleaned with a spatula.
• Mould release wax was applied to the entire mould, with a greater proportion at the corners to prevent the resin from sticking to the mould.

2.5. Production of test specimens (test material).
• The vegetable fibre was subjected to a heat press for complete drying.
• For specimens dimensioning, vegetable fibre layer thickness was represented approximately 3 layers to have the desired thickness, since the minimum thickness to have is 3 mm from the ISO 3795 standard, but the thickness with which it was worked was 10 mm.
The 3 layers of vegetable fibre were weighed, this represented 70% of the volumetric fraction of the composite material, it should be stressed that this was done for each combination.

30% was distributed between the resin and the fireproofing with the following configuration: (27% - 3%), (24% - 6%), (21% - 9%) respectively. A rule of three was used to calculate these percentages.

Taking for example the combination A of the study, with a configuration: 27% polyester resin, 70% reinforcement and 3% fireproof (Aluminium Hydroxide), the following is obtained. Weight of the 3 layers of vegetable fibre = 0.925 kg as follow:

- Reinforcement = Plant fibre = 70% of the volumetric fraction
- Matrix = Polyester resin = 27% of the volume fraction
- Weight of polyester resin = X
- Fireproof = 3% of the volumetric fraction
- Weight of the fire retardant = Z

\[
0.925 \text{ Kg} = 70\% \text{ and } X = 27\%
\]

\[
X = (0.925 \text{ Kg} * 27\%) / 70\% \tag{1}
\]

\[
X = 0.356 \text{ Kg}
\]

\[
0.925 \text{ Kg} = 70\% \text{ and } Z = 3\%
\]

\[
Z = (0.925 \text{ Kg} * 3\%) / 70\% \tag{2}
\]

\[
Z = 0.039 \text{ Kg}
\]

In other words, for the 5 replicas of each specimen was needed 0.356 Kg of polyester resin and 0.039 Kg of fireproof (aluminium hydroxide), because the 400 mm long by 400 mm wide mould was used. Then make the individual cut of each specimen with its due dimensioning according to ISO 3795, this means that for each individual specimen, the proportion was given according to Tab. 1 and 2.

| Table 1. Quantity of kilograms to be used to make the specimens (test material) with polyester resin and aluminium hydroxide |
|---|---|---|---|
| Combination | 70% FCI | 27% RP | 3% HA |
| A | 0.185 kg | 0.0713 kg | 0.0079 kg |
| Combination | 70% FCI | 24% RP | 6% HA |
| B | 0.185 kg | 0.0634 kg | 0.0158 kg |
| Combination | 70% FCI | 21% RP | 9% HA |
| C | 0.185 kg | 0.0555 kg | 0.0237 kg |

\(^a\) FCI= Intermediate calamagrostis fiber; \(^b\) RP= Polyester resin; \(^c\) HA= Aluminium Hydroxide

| Table 2. Quantity of kilograms to be used to make the specimens (test material) with polyester resin and Magnesium hydroxide |
|---|---|---|---|
| Combination | 70% FCI | 27% RP | 3% HM |
| D | 0.185 kg | 0.0713 kg | 0.0079 kg |
| Combination | 70% FCI | 24% RP | 6% HM |
| E | 0.185 kg | 0.0634 kg | 0.0158 kg |
| Combination | 70% FCI | 21% RP | 9% HM |
| F | 0.185 kg | 0.0555 kg | 0.0237 kg |

\(^a\) FCI= Intermediate calamagrostis fiber; \(^b\) RP= Polyester resin; \(^c\) HA= Aluminium Hydroxide
• To these combinations a Methyl Ethyl Ketone Peroxide (MEC) catalyst was added to steel the drying process of the samples for which it was calculated, 20% of the weight of the resin to be used.
• For the freezing process, the sample containing aluminium hydroxide was exposed to room temperature for 15 to 30 minutes, while the one containing magnesium hydroxide was subjected to a time of 60 to 90 minutes.
• For the curing time, it was left to dry for a period of approximately 3 hours, for the specimens (test material) containing aluminum hydroxide and approximately 7 hours, for the specimens (test material) containing magnesium hydroxide.
• Once the material has cured, the specimens (test material) were removed from the mould and then cut, sanded and measured to check their dimensions and compliance with the standard.

2.6. Specimen sizing (test material)
The ISO 3795 standard was used to size the specimens (test material) and it was established that 5 specimens should be made for the test, complying with the following dimensions, length: 356 mm, width: 60 mm and in the case of the thickness it was 10 mm. It is recommended 2 layers to be used in the study [10], but in this case, 3 layers were used to achieve the desired thickness.

| Combination | Composition | Average thickness (mm) |
|-------------|-------------|------------------------|
| A           | 70% FCI⁺ + 27% RP⁺ + 3% HA⁺ | 10                     |
| B           | 70% FCI⁺ + 24% RP⁺ + 6% HA⁺ | 10                     |
| C           | 70% FCI⁺ + 21% RP⁺ + 9% HA⁺ | 10                     |
| D           | 70% FCI⁺ + 27% RP⁺ + 3% HM⁺ | 10                     |
| E           | 70% FCI⁺ + 24% RP⁺ + 6% HM⁺ | 10                     |
| F           | 70% FCI⁺ + 21% RP⁺ + 9% HM⁺ | 10                     |

*a* FCI= Intermediate calamagrostis fiber

*b* RP= Polyester resin

c HA= Aluminium Hydroxide

d HM= Magnesium Hydroxide

2.7. Flammability Index Test.
Corresponding to the ISO 3795 standard, the flammability test was carried out on five samples of each material, each of which met the following dimensions: 60 mm wide by 356 mm long and with a minimum thickness of 3 mm and no more than 13 mm, as the method is not applicable outside that range. Fourteen marker threads were drawn and fixed perpendicularly to the sample at the indicated points.
• The first point was at 40 mm,
• From the second point to the thirteenth point it was 20 mm,
• Finishing the fourteenth point with 14 mm

Having a total of 274 mm, according to the standard.

1. This test was carried out inside a gas extraction chamber. Inside the combustion chamber, the individual specimens (test material) were placed horizontally on their respective U-shaped support (Svebrant, 2011).
2. A bunsen burner and LPG were used to generate the flame.
3. The samples were exposed to an initial flame for 15 seconds inside the combustion chamber so that the flame acted on the free edge of the sample.
4. After a series of tests, it was allowed to cool down, so that the temperature of the combustion chamber and the sample holder was below 30°C before starting the next test (Serrano Aguilar & Padilla Porras, 2013).
5. From the following equation Eq. 3, the burning rate (B) was determined in mm/min.
Combustion rate

\[ B = 60 \frac{d}{t} \] (3)

where: \( d \) = length of distance burned (mm) and \( t \) = time it takes for that distance to burn. (s)

2.8. Test to determine the presence of carbon monoxide (CO).

The test to determine the presence of carbon monoxide was carried out since when making combustion toxic gases are released to the environment what was wanted to verify with this test was that the flame-retardants used in the fiber do not generate these polluting gases for what it was resorted to the taking of samples to then check indicators, with tables established by the Ministry of the Environment of Ecuador.

The gas analyser FYRITE INSIGHT PLUS was used, as follow:

1. The sampling probe was placed at the first measuring point in such a way as to allow at least three measurements.
2. Measurement parameters were set.
3. Extraction systems were switched on.
4. Flammability test started.
5. The combustion test was carried out, taking CO measurements every 80 seconds once the test piece had been lit.
6. Finally, the instrument was purged for the next measurements [11].

3. Results and Discussions

3.1 Flammability test.

The flammability test was carried out to help monitor combustion processes of the specimens (test material) effectively to measure the speed of combustion, as well as the production of carbon monoxide.

The material was evaluated in the horizontal flammability chamber of the Faculty of Mechanical Engineering of the Technical University of Ambato, 7 tests were carried out, one control and two types of fire retardants (Aluminum Hydroxide and Magnesium Hydroxide), each with 3 different concentrations at 3, 6 and 9 percent, these values established according to other results [12].

The combustion process took place by deflagration since the flame front moved at a constant speed, this combustion took place by the heating in the form of conduction-convection of the specimen and the chain reactions that advanced the process of each of the specimens (test material) [13]. Table 4 displays the summary of results of the flammability index of the 7 combinations, Test Bench.

Table 4: Summary of flammability index results

| Combination | Flammability Index Average (mm/min) |
|-------------|-----------------------------------|
| No fire-retardant | 302,398 |
| A_a | 259,052 |
| B_b | 253,728 |
| C_c | 190,98 |
| D_d | 365,688 |
| E_e | 315,192 |
| F_f | 234,178 |

\(^a\) Combination A: 70% FCI, 27% RP, 3% HA;
\(^b\) Combination B: 70% FCI, 24% RP, 6% HA;
\(^c\) Combination C: 70% FCI, 21% RP, 9% HA;
\(^d\) Combination D: 70% FCI, 27% RP, 3% HM;
\(^e\) Combination E: 70% FCI, 24% RP, 6% HM;
\(^f\) Combination F: 70% FCI, 21% RP, 9% HM.
From Figure 3, it can be determined that the surface of each bar is proportional to the frequency of the values represented, thus obtaining a panoramic view of the distribution of the samples. The flame retardants that are working effectively are aluminium hydroxide at 3, 6 and 9 percent, while magnesium hydroxide is only effective at 9 percent, since this hydroxide at the concentrations of 3 and 6 percent has a combustion rate greater than that of the control, which means that they are not effective.

![Image](image.png)

**Figure 3.** Histogram of flammability index results

It can also be determined that the best concentration to work with these fire retardants is the aluminium hydroxide at 9 percent since it presents a self-extinguishing behaviour, which makes it ideal and in comparison, to a study made by [12] these hydroxides present similar characteristics being the aluminium hydroxide at 9 percent the best combination.

### 3.2 Statistical analysis

Null hypothesis = All averages are equal

Alternate hypothesis= At least one average is different

Significance level $\alpha = 0.05$

| Table 5. ANOVA: Combustion rate B(mm/min) vs. Concentration |
|---|---|---|---|---|
|  | GL | SC Adjusted | MC Adjusted | F-value | p-value |
| Concentrations | 6 | 10105 | 16684.1 | 45.85 | 0.000 |
| Error | 28 | 10190 | 363.9 |
| Total | 34 | 110295 | |

Since the p value is less than the significance level (0.05), the null hypothesis is rejected so at least one mean is different, as presented on Table 6.

| Table 6. Averages of Burning Rate B(mm/min) vs. Concentration |
|---|---|---|---|
| Concentration | N | Mean | Standard Deviation |
| AL 3 | 5 | 259.1 | 45.2 | (241.6; 276.5) |
| AL 6 | 5 | 253.728 | 1.291 | (236.252; 271.204) |
| AL 9 | 5 | 190.98 | 2.32 | (173.50; 208.46) |
| Control | 5 | 302.40 | 8.82 | (284.92; 319.87) |
| MG 6 | 5 | 315.19 | 14.34 | (297.72; 332.67) |
| MG 9 | 5 | 234.18 | 9.08 | (216.70; 251.65) |
| MG3 | 5 | 365.69 | 11.56 | (348.21; 383.16) |

Grouped data standard deviation = 19.0767
Figure 4 shows that, in relation to the control, the combination that works more efficiently is aluminium hydroxide at 9 percent, which corroborates the regression analysis, and previous studies have shown similar results, as mentioned above [14].

![Figure 4. Burn rate ranges (mm/min) vs. Concentrations](image)

The fire retardants that are found above the control flaps have a higher combustion rate, so the fire retardant does not work effectively and therefore the use of these would not be appropriate [3].

### 3.3 Multiple Dunnet comparisons with a control

**Table 7. Multiple Dunnet comparisons with a control**

| Concentration | N  | Mean   | Group |
|---------------|----|--------|-------|
| Control       | 5  | 302.40 | A     |
| MG 3          | 5  | 365.69 |       |
| MG 6          | 5  | 315.19 | A     |
| AL 3          | 5  | 259.1  |       |
| AL 6          | 5  | 253.728|       |
| MG 9          | 5  | 234.18 |       |
| AL 9          | 5  | 190.92 |       |

Averages not labelled with the letter A are significantly different from the average of the control level, indicating once again that Mg 6 has a significant similarity to the control average and does not function properly, so it has no effect when used. In addition, Mg 3 is not labelled with the letter A as this is significantly different but compared to the control it has a much higher combustion rate so it does not function effectively either.

**Table 8. Simultaneous Dunnett tests for the average level - Control average**

| Level difference | Difference from averages | EE difference | IC 95%       | T Value | Adjusted p-value |
|------------------|--------------------------|---------------|--------------|---------|-----------------|
| AL 3 - Control   | -43.3                    | 12.1          | (-76.3; -10.4)| -3.59   | 0.006           |
| AL 6 - Control   | -48.7                    | 12.1          | (-81.6; -15.7)| -4.03   | 0.002           |
| AL 9 - Control   | -111.4                   | 12.1          | (-144.4; -78.5)| -9.23   | 0.000           |
| MG 6 - Control   | 12.8                     | 12.1          | (-20.2; 45.7) | 1.06    | 0.782           |
| MG 9 - Control   | -68.2                    | 12.1          | (-101.2; -35.3)| -5.65   | 0.000           |
| MG 3 - Control   | 63.3                     | 12.1          | (30.3; 96.2)  | 5.25    | 0.000           |
If an interval does not contain zero, the corresponding mean is significantly different from the control mean, yielding that the best combination is 9 percent Aluminum Hydroxide. This compound presents a self-extinguishing behavior which makes it ideal. The fireproofing action of aluminum hydroxide is based on the thermal elimination of chemically bonded water in case of fire at temperatures in the range of 200 to 400 °C. These compounds decompose through an endothermic reaction, releasing water vapour that removes heat and reduces the formation of combustible gases, as well as forming a protective layer on the surface of the material that acts by preventing the thermal degradation from being prolonged. [1].

The flame propagation in the analysed samples was symmetrical and kept within the limits indicated by the standard. This endothermic decomposition of the aluminium hydroxide consumes energy, due to the cooling of the polymer surface. [15] Aluminium hydroxide acts essentially by forming a barrier containing the degradation products and diluting the concentration of combustible gases. [16]

One of the reasons why the 3 and 6 percent Magnesium Hydroxide did not present a positive efficiency is due to the fact that when the combination with the polyester resin was made, it had a high viscosity and when the sample was homogenized it was difficult, since its molecular weight is 58.3197 g/mol which makes it very light, producing lumps, thus causing an incorrect adhesion between them. [17] Furthermore, that a higher percentage of the catalyst Methyl Ethyl Keton Peroxide was used, thus using not 20% of the weight of the resin used, but rather 30% of it, this was because the curing time was too long and by means of this catalyst the reaction was accelerated. Another reason why I do not present a positive efficiency, was because this type of fireproofing requires a high amount of concentration as mentioned [18], so it is determined that at 9 percent this Hydroxide has a positive response, besides being the best combination, since the concentration is higher and provides the fireproofing properties that are required.

3.4 Test to determine the presence of carbon monoxide (CO).
The gas analyser FYRITE INSIGHT PLUS was used because it analyses gases that are products of a combustion, its analysis is limited to the determination of CO, CO₂, O₂, ambient temperature, gas temperature, its adaptability with the EPA 40 CFR method 60 Annex A, makes it the ideal equipment for the analysis of the combustion processes that are generated in the flammability chamber, as on Table 9 below.
Table 9. CO analysis in combustion

| Sample | Control (PPM) | A (PPM) | B (PPM) | C (PPM) | D (PPM) | E (PPM) | F (PPM) |
|--------|---------------|---------|---------|---------|---------|---------|---------|
| 1      | 2             | 6       | 4       | 1       | 2       | 1       | 12      |
| 1      | 2             | 8       | 5       | 1       | 8       | 5       | 20      |
| 1      | 3             | 8       | 6       | 2       | 13      | 5       | 27      |
| 2      | 2             | 7       | 1       | 1       | 5       | 1       | 0       |
| 2      | 2             | 8       | 0       | 1       | 4       | 5       | 0       |
| 2      | 2             | 8       | 0       | 2       | 9       | 4       | 0       |
| 3      | 3             | 6       | 3       | 1       | 3       | 3       | 1       |
| 3      | 4             | 7       | 3       | 0       | 6       | 8       | 3       |
| 3      | 5             | 8       | 3       | 0       | 2       | 8       | 3       |
| 4      | 2             | 5       | 1       | 1       | 5       | 1       | 10      |
| 4      | 3             | 18      | 1       | 2       | 6       | 5       | 12      |
| 4      | 4             | 19      | 1       | 2       | 8       | 6       | 15      |
| 5      | 3             | 6       | 3       | 0       | 6       | 2       | 12      |
| 5      | 4             | 6       | 4       | 1       | 8       | 5       | 15      |
| 5      | 4             | 7       | 4       | 1       | 9       | 5       | 22      |
| Average| 3             | 8       | 3       | 1       | 6       | 4       | 10      |

Note: FCI= Fiber of intermediate calamagrostis; RP= Polyester resin; HA= Aluminum hydroxide; HM= Magnesium hydroxide.

Combination A: 70% FCI, 27% RP, 3% HA; Combination B: 70% FCI, 24% RP, 6% HA; Combination C: 70% FCI, 21% RP, 9% HA; Combination D: 70% FCI, 27% RP, 3% HM; Combination E: 70% FCI, 24% RP, 6% HM; Combination F: 70% FCI, 21% RP, 9% HM.

The gas analyser FYRITE INSIGHT PLUS was used because it analyses gases that are products of a combustion, its analysis is limited to the determination of CO, CO2, O2, ambient temperature, gas temperature, its adaptability with the EPA 40 CFR method 60 Annex A, makes it the ideal equipment for the analysis of the combustion processes that are generated in the flammability chamber.

The percentage of acceptance or permissible error for the reading according to the analyser is 10% for readings between 0 and 200 PPM. As it is observed in figure 6 the combination that presents a smaller value of CO is the aluminum hydroxide to 9 percent, being this ideal to reduce the environmental impact that this one has since the aluminum oxide that remains as residue has a high specific surface area and absorbs compounds of polycyclic and aromatic hydrocarbons formed in the combustion of the polymer. As a result, these compounds are removed from the combustion process. Since polycyclic and aromatic hydrocarbon compounds are constituents of black smoke from a fire, aluminium hydroxide also contributes to reducing the density of the smoke [15].

![Figure 6. Analysis of CO in combustion](image-url)
These CO values in the combustion of intermediate calamagrostis, do not exceed the permissible limits and are therefore considered environmentally friendly, as the maximum concentration in 1 hour of carbon monoxide must not exceed thirty thousand micrograms per cubic metre 30 000 µg/m³[19].

The maximum concentration of the combinations was 9 percent magnesium hydroxide with a value of 11432.7 µg/m³, this is well below the maximum value, without the need to implement treatment protocols or improvement in the quality of air emitted into the atmosphere [20]

4. Conclusions
The flammability analysis was carried out using the ISO 3795 standard, which is the best procedure for preparing the test material, obtaining the appropriate sizing, so that the specimens can be burnt. Out of 30 test pieces, the efficiency of inorganic fire retardants applied to the combustion speed of intermediate calamagrostis in the Ecuador’s moorlands was determined. Statistical calculations showed that the best combination was C (70% ICF, 21% PR, 9% AH), resulting in a combustion rate of 190.98 mm / min and self-extinguishing capacity. In addition, a positive answer to the effectiveness was verified for Aluminium Hydroxides to all the proposed concentrations, whereas for Magnesium Hydroxide the effectiveness was positive only for the combination F. These results were satisfactory when delaying the combustion flame in the test tubes that were the material of test, this was given by means of the use of the horizontal combustion chamber to controlled environmental conditions under the norm ISO 3795. The results of the carbon monoxide determination test were evaluated for the 35 prepared samples from the moorlands of Chimborazo, Ecuador. Combination C and combination F have a gray-dark coloring in the gas product of combustion. These results were obtained by using the horizontal combustion chamber under controlled environmental conditions and the FYRITE INSIGHT PLUS gas analysis measurement equipment. Finally, an average decrease of 50% in CO generation and the amount of smoke was determined.

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