The influence of weather conditions on the effectiveness of preventive fire retardant treatment of forests

V M Gedjo

Department of Technology of Wood and Cellulose Composite Materials, St. Petersburg State Forest Technical University, 5 Institutsky Lane, St.-Petersburg 194021, Russian Federation

Corresponding email: 9217407087@mail.ru

Abstract. We discuss the influence of weather conditions (increased humidity, rain, snow) on the effectiveness of preventive fireproof treatment of forests and soil with amidophosphate KM. The dependence of the required level of fireproof treatment of forests and soil on the amount of precipitation during one calendar year has been established. We also estimated the minimum required amount of amidophosphate KM for repeated preventive treatment of forests and ground cover. Here we present the results of tests carried out in the field.

1. Introduction

Forest fires are natural disasters caused by uncontrolled forest burning in large forest areas. As a rule, large fires occur in remote forest areas. Therefore the delivery of fire extinguishing equipment and fire extinguishing agents to those areas can be difficult, resulting in serious problems with the mechanization and suppression of forest fires. In the presence of a sufficiently large source of ignition and in adverse weather conditions, such as strong winds and lack of precipitation, the spread of a forest fire becomes uncontrollable, that is, it is not possible to localize and extinguish the source of ignition. This leads to the spread of fire over a large area of forest, as a result of which we suffer not only significant material losses, due to the loss of marketable forest products, but also face the prospect of severe environmental consequences. All these factors indicate that it is advisable and even necessary to carry out preventive fire-retardant treatment of forests and ground cover to prevent the occurrence of forest fires.

Given the high cost of fire retardants that can be used for preventive treatment, it is necessary to identify the treatment sites and estimate the minimum required amount of fire retardant providing the required level of fire protection of forests and ground cover. The required level of fire protection implies the impossibility of self-burning of treated objects when exposed to fire sources [1].

It is necessary to study the effect of precipitation (rain and snow) and increased air humidity on the change in the level of fire protection and, if necessary, estimate the required amount of fire protective substance for additional fireproof treatment of forests. Given that approximately 95% of forest fires arise from careless handling of fire (the human factor), preventive forest treatment must be carried out in places with the highest concentration of people (i.e., in recreational areas, near settlements, along forest roads and public roads). It is important to carry out the preventive treatment of places that might have sources of ignition and where the occurrence of fires poses an immediate threat to life.
2. Methods and Materials

For preventive treatment of forests, we propose an aqueous solution of amidophosphate KM [2]. This is a condensation product of concentrated orthophosphoric acid and urea with a ratio of the main reaction components of phosphorus and nitrogen 1:3 [3]. Trees and shrubs are treated with 25%, and ground cover and dry grass with 30% aqueous solution of amidophosphate KM.

As model objects of preventive fire-proof treatment, we used living spruce trees (30 years old), pine trees (35 years old), birch trees (30 years old), aspen trees (30 years old), as well as dead spruce trees, living shrubs of common juniper, and ground cover consisting of dry grass, needles, foliage, moss and twigs only.

We treated trees and shrubs, and ground cover with 25% and 30% water solutions of amidophosphate KM, respectively, using the RP-18 Ermak backpack, which is used to extinguish low and medium intensity ground fires [4].

Ignition of the model objects was carried out using an A3-4 incendiary device commonly employed for the oncoming fire during extinguishing forest fires and artificially created from dry branches, grass and moss bonfires. The trunks and branches of trees and shrubs were exposed to fire from the incendiary device for five minutes, and the impact of bonfires on the ground cover lasted for 50-60 minutes.

The level of fire protection was evaluated by the amount of amidophosphate KM deposited on the surface of the treated objects and the presence or absence of self-combustion and flame or flameless (smoldering) burning.

3. Results and Discussion

As an initial component for the fireproof treatment of the model objects, a 50% aqueous solution of amidophosphate KM was used. The solution was prepared in the chemical workshop of the Lisinsky training experimental forestry unit; the technical characteristics of the solution are given in table 1. For a more uniform treatment, this solution was diluted with water to a concentration of 30% or 25%.

We treated trees and shrubs with a 25% aqueous solution of the fire retardant, and the ground cover and dry grass, with a 30% solution. The treatment was carried out by fine spraying on the lower part of the trunk and lower branches of trees, from the root and to a height of up to 3 meters, using a RP-18 backpack fire sprayer. Shrubs, dry grass and ground cover were treated completely. Then, the treated objects were left to dry for three hours, which allowed the amidophosphate KM active ingredient to be fixed on the surface of the treated objects.

The degree of flame retardant treatment was evaluated by the amount of amidophosphate KM deposited and fixed on the surface of the objects studied. The amount of KM was determined by chemical analysis of the content of phosphorus and nitrogen in aqueous extracts of selected samples from the model objects before and after the treatments.

The degree of fire protection was evaluated visually by the results of exposure of the model objects to fire sources. Tree trunks, branches and shrubs were exposed to fire with an A3-4 incendiary device for 5 minutes, and dry grass and ground cover were set on fire using bonfires lit on them for 50-60 minutes. The amount of the fixed amidophosphate KM and the results of the fire tests are presented in table 2.

Table 1. Technical characteristics of aqueous solutions of the flame retardant.

| Item No. | Composition of the flame retardant | Concentration, % | Density, g/cm³ | pH  | Color       |
|----------|-----------------------------------|------------------|----------------|-----|-------------|
| 1        | Amidophosphate + Water            | 50               | 1.24           | 6.5 | Colorless   |
| 2        | Amidophosphate + Water            | 30               | 1.14           | 6.6 | Colorless   |
| 3        | Amidophosphate + Water            | 25               | 1.10           | 6.6 | Colorless   |
Table 2. Fire test results after a single treatment by amidophosphate KM.

| Item No. | Examined object  | The amount of amidophosphate KM, mg/cm² | Fire test results |
|----------|------------------|----------------------------------------|------------------|
|          |                  |                                        | Flame burning    | Flameless burning (smoldering) |
| 1        | Spruce trunk     | 2.5                                    | Absent           | Present                        |
| 2        | Spruce branches  | 2.1                                    | Absent           | Present                        |
| 3        | Pine trunk       | 2.4                                    | Absent           | Present                        |
| 4        | Pine branches    | 2.0                                    | Absent           | Present                        |
| 5        | Birch trunk      | 2.5                                    | Absent           | Present                        |
| 6        | Birch branches   | 2.2                                    | Absent           | Present                        |
| 7        | Aspen trunk      | 2.5                                    | Absent           | Present                        |
| 8        | Aspen branches   | 2.2                                    | Absent           | Present                        |
| 9        | Juniper shrub    | 2.1                                    | Absent           | Present                        |
| 10       | Dry grass        | 1.7                                    | Present          | Present                        |
| 11       | Ground cover     | 1.9                                    | Present          | Present                        |

Our results demonstrate that amidophosphate KM fixed on the samples did not provide a sufficient level of fire protection – we observed flameless burning of all samples, and the ground cover and dry grass ignited and supported the combustion process. All these factors indicate that the fire retardant does not provide the fire protection according to the mechanism described in [5]. The amount of amidophosphate KM fixed on dry grass and on the ground cover was lower compared to that fixed on tree trunks, which is explained by the different absorbency and very different types of the treated surface.

To increase the fire protection of the model objects, they were re-treated with amidophosphate KM according to the procedure described above. The results are presented in table 3. Re-treatment was carried out a day after the initial treatment. After complete drying, the model objects were exposed to fire in the same way as after the initial treatment.

Table 3. The results of fire tests after the second treatment with amidophosphate KM.

| Item No. | Examined object  | The amount of amidophosphate KM, mg/cm² | Fire test results |
|----------|------------------|----------------------------------------|------------------|
|          |                  |                                        | Flame burning    | Flameless burning (smoldering) |
| 1        | Spruce trunk     | 5.1                                    | Absent           | Absent                         |
| 2        | Spruce branches  | 4.3                                    | Absent           | Absent                         |
| 3        | Pine trunk       | 5.0                                    | Absent           | Absent                         |
| 4        | Pine branches    | 4.2                                    | Absent           | Absent                         |
| 5        | Birch trunk      | 5.2                                    | Absent           | Absent                         |
| 6        | Birch branches   | 4.5                                    | Absent           | Absent                         |
| 7        | Aspen trunk      | 5.1                                    | Absent           | Absent                         |
| 8        | Aspen branches   | 4.5                                    | Absent           | Absent                         |
| 9        | Juniper shrub    | 4.3                                    | Absent           | Absent                         |
| 10       | Dry grass        | 3.6                                    | Absent           | Absent                         |
| 11       | Ground cover     | 3.9                                    | Absent           | Absent                         |

As a result of the tests performed, we came to the conclusion that a repeated fire retardant treatment allowed to double the amount of amidophosphate KM fixed on the model objects. This amount turned out to be sufficient for the flame retardant to act as a catalyst for changing the mechanism of thermal decomposition of carbohydrates and increase the yield of reaction water. As a result of the presence of amidophosphate KM on plants exposed to fire, the mechanism of thermal decomposition of plant raw materials changes in the direction of a significant reduction in the yield of combustible volatile
products (causing flame burning) and a significant decrease in the thermal effect, to a level lower than the thermal effect of the ignition pulse. With this ratio of thermal effects, the development of combustion is impossible [6]. All this is confirmed by the results of fire tests aimed to study the influence of fire sources on fire-protected plant objects; the latter that did not support independent burning and the fire quickly died out.

It was important to understand how long the treated objects will retain their fire protection under the influence of atmospheric precipitation and high humidity, and also taking into account the fact that those were living plants that change throughout the year (foliage changes, new grass grows, etc.). The answers to these questions were not only of scientific interest, but were also very important from a practical point of view, in particular for scheduling the frequency of repeated fire retardant treatments. It was important to determine not only the time during which a sufficient level of fire protection of the model objects could be maintained, but also to estimate the minimum quantity of fire retardant required for treatment, which would allow to achieve the required level of fire protection.

Studies conducted the following year showed that some model objects lost their resistance to fire due to a decrease in the concentration of the fire retardant amidophosphate KM on their surface (table 4). Due to the low solubility of amidophosphate KM in water, from 90% to 95% of the fire retardant applied to the tree trunks, shrubs, ground cover, tree branches and needles remained on their surfaces. This amount was enough to maintain their resistance to fire. A new treatment was necessary only in the case of foliage and dry grass that grew within a year after the initial treatment. Given the previous fire retardant treatment of branches and litter under dry grass, a single treatment was sufficient. The data are presented in table 5.

Table 4. The impact of precipitation on the level of fire protection of the model objects.

| Item No. | Examined object          | The amount of amidophosphate KM, mg/cm² | Fire test results |
|---------|--------------------------|----------------------------------------|------------------|
|         |                          |                                        | Flame burning    | Flameless burning (smoldering) |
| 1       | Spruce trunk             | 4.8                                    | Absent           | Absent                        |
| 2       | Spruce branches          | 4.0                                    | Absent           | Absent                        |
| 3       | Pine trunk               | 4.8                                    | Absent           | Absent                        |
| 4       | Pine branches            | 4.0                                    | Absent           | Absent                        |
| 5       | Birch trunk              | 4.9                                    | Absent           | Absent                        |
| 6       | Birch branches           | 2.3                                    | Absent           | Present                       |
| 7       | Aspen trunk              | 4.8                                    | Absent           | Absent                        |
| 8       | Aspen branches           | 2.7                                    | Absent           | Present                       |
| 9       | Juniper shrub            | 3.9                                    | Absent           | Absent                        |
| 10      | Dry grass                | 0.7                                    | Present          | Present                       |
| 11      | Ground cover             | 3.5                                    | Absent           | Absent                        |

Table 5. The results of fire tests after repeated treatment (after 1 year) with amidophosphate KM.

| Item No. | Examined object        | The amount of amidophosphate KM, % | Fire test results |
|----------|------------------------|-----------------------------------|------------------|
|          |                        |                                   | Flame burning    | Flameless burning (smoldering) |
| 1        | Birch branches         | 4.5                               | Absent           | Absent                        |
| 2        | Aspen branches         | 4.3                               | Absent           | Absent                        |
| 3        | Dry grass              | 3.2                               | Absent           | Absent                        |

The study showed that a sufficient level of fire protection can be achieved by a double fire retardant treatment of trees, shrubs, forest ground cover and dry grass with an aqueous solution of
amidophosphate KM, as a result of which all treated objects would not support the process of independent burning. All this indicates that the agent can be effectively used as a fire retardant for preventative forest treatment. The consumption of amidophosphate KM solution with a concentration of 25% for double treatment of trees and shrubs and with a concentration of 30% for the treatment of ground cover and dry grass is 200 ml/m². Taking into account the low solubility of amidophosphate KM salts in water, repeated annual fire retardant treatment of trees, shrubs and ground cover is not required. It is enough to carry out a single treatment every three years. When annual plants (grass in particular) and foliage are considered, it is sufficient to treat them once a year. This is due to the fact that the treated fallen leaves and dry grass retain their fire retardant properties in the forest ground cover and in the layer under the grass. Given the fact that amidophosphate KM contains phosphorus and nitrogen in a form close to that of standard organic fertilizers, they are effective for fertilizing plants, i.e. their application does not have any negative environmental consequences [7].

4. Conclusions
- To reduce the economic and environmental losses from forest fires, it is advisable to carry out preventive fire-retardant treatment of forests.
- Amidophosphate KM can be used as an effective and environmentally friendly fire retardant.
- The influence of atmospheric precipitation and increased humidity on the fire retardant properties of amidophosphate KM-treated plants and soil is insignificant (5-10% loss); therefore repeated treatments are not required.
- To provide annual plants and foliage with protection against fire, annual treatment with a fire retardant is required.

References
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