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Sumi, K.

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FOREST FIRE RETARDANTS

by

K. Sumi

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PREFACE

The Fire Research Section of the Division of Building Research in 1959 began studies of the use of retardants and suppressants for forest fire control. These studies were undertaken following a request from the Associate Committee on Forest Fire Protection on which provincial and federal forestry agencies are represented.

The range of possible studies is broad. Those made to date and now reported have been largely exploratory, involving consideration of the general problem, examination of laboratory evaluation procedures and investigation of one type of retardant.

The author, a chemical engineer, is a research officer with the Fire Research Section, having responsibility for work on fire extinguishment.

Ottawa,
May 1963

N. B. Hutcheon,
Assistant Director.

FOREST FIRE RETARDANTS

by

K. Sumi

The Division of Building Research of the National Research Council commenced studies in 1959 concerning the development of effective retardants and suppressants for use in forest fire control. These studies were undertaken following a request from the Associate Committee on Forest Fire Protection of the National Research Council that indicated potential uses for which new retardants and suppressants should be considered:

(1) to retard the progress of fire by preparing fire lines at some distance in advance of a forest fire;

(2) to extinguish fire by direct application on a fire front; and

(3) to protect "high-value" areas by making these areas less susceptible to ignition.

Fire retardant and fire suppressant are defined as follows(1):

A "retardant" is used to treat the fuels at or ahead of the flame front so that the combustion process is modified when fire reaches the treated fuel.

A "suppressant" is used to extinguish the flaming or glowing phases of combustion by direct application to the burning fuel.

Retardants are required for the preparation of fire lines and treatment of high-value areas, and suppressants are required for direct application on a fire front. An agent effective as both a retardant and a suppressant would be ideal.

The initial investigation was limited to retardants. A review of literature on retardants, the development of a laboratory test, and experimental work dealing with one type of retardant for possible use in forest fire control are described.

SCOPE OF THE PRESENT INVESTIGATION

The size of a fire, the density, moisture content, arrangement of available fuel, and wind and weather conditions all affect the progress of a fire. In addition, the suppression methods employed, the size of the fire-fighting crew and the equipment available to them are governing factors.

Because there are so many variables that can influence the progress of a forest fire it was decided to limit the scope of the present investigation to the examination of a potential retardant for a specific forest situation. The conditions under which the new retardants were examined are given below.

The Fire

The fire to be considered is a small surface fire, defined as "a fire that burns surface litter, other loose debris of the forest floor, and small vegetation."[2] The crew available for extinguishing the fire or retarding its spread is small, and large mechanical equipment is not available.

The Forest Floor

The depth of fuel on the forest floor is not great, and a ground fire below the retardant is not, therefore, a serious problem. Ground fire is defined as "a fire that consumes the organic material beneath the surface litter of the forest floor."[2] This limitation was imposed because the relative effectiveness of different types of retardants is dependent on the depth of fuel.

Specific Purpose of the Agent

The potential use of an agent as a retardant for the preparation of fire lines should be considered.

The most common method of preparing a fire line is to remove all fuel in advance of the fire in order to break the fuel continuity in the forest. In constructing a fire line a crew will cut bushes, small trees and logs along a given line, and dig or remove surface litter along a strip a foot or more in width down to mineral soil. Water or retardants, when available, can be used as an alternative method of preparing a fire line or in conjunction with the method described. Hand tools are widely used for the preparation of fire lines because large mechanical equipment such as plows and bulldozers are often not available. It is under such circumstances that the potential use of retardants offers some promise.

LITERATURE REVIEW

The use of chemicals to suppress or retard fires has been a subject of research for over 100 years[1], although their application to forest fire control did not receive a great deal of attention until relatively recently.

Since 1931, however, the U.S. Forest Service has been engaged in laboratory and field studies to examine the potential use of various chemicals for fire suppression. Chemicals that have been examined include potassium carbonate, calcium chloride, monoammonium phosphate, diammonium phosphate, lime, talc, cement, wetting agents, sodium calcium borate and bentonite.

Use of new agents against actual fires is still very limited. There are various reasons for this:

(1) the cost of chemicals and the expense of transporting them,

(2) the difficulties encountered in handling chemicals and using new agents with conventional equipment, and

(3) the relatively small difference in effectiveness of the new agents as compared with water alone.

Water is a good suppressant and a useful retardant, but for forest fire control it has certain limitations; its effect as a retardant for the preparation of fire lines is only temporary, and it is usually needed in large quantities for extinguishing forest fires. This need for large quantities of water is often a serious problem, because water is not always readily available in many forest locations. The search, therefore, for new retardants more persistent than water and for suppressants that will put out more fire per unit of weight has been receiving increasing attention in recent years.

Developments in this field include the use of a viscosity additive to improve the fire fighting characteristics of water, and the use of a gel of alginate (extracted from seaweed) and calcium chloride as a retardant. Interest in a suppressant that contains a viscosity additive results largely from studies carried out by Grove and his associates at the Syracuse University Research Institute[3]. The use of diammonium phosphate solution thickened with a viscosity additive is at present receiving some consideration for potential use as both a retardant and a suppressant. Various theories have been advanced in attempts to explain the behaviour of different types of retardants on the combustion of wood[4]; but because of the lack of experimental work to establish properly the validity of these theories, the mechanism of the influence of retardants is highly speculative.

The behaviour of several different types of retardants is discussed below in the light of present knowledge:

1.) Treatment with chemicals that melt at some elevated temperature and coat the combustible material with a liquid or glassy layer. - The mechanism of the effect of this type of retardant is believed to be prevention of the escape of volatile combustion products from the wood and any access of oxygen to the wood. Mixtures of borax and boric acid are considered to act in this way.

2.) Treatment with chemicals that intumesce, i.e. form foams stable at elevated temperatures. - This mechanism is similar to the preceding example. Materials that intumesce may be more effective than glazes; the foam serves as a barrier to air and flame and provides thermal insulation. Fire retardant paints that intumesce with heat are considered to act in this way.

3.) Treatment with chemicals that decompose or change state to absorb enough heat to prevent the combustible material from reaching ignition temperature. - Water acts in this way. Few substances have endothermic heats of transition or of decomposition comparable to the heat of vaporization of water. Protection is at best temporary, because exhaustion of the supply of water leaves the wood subject to combustion as before.

4.) Treatment with retardants that may dilute the combustible gases sufficiently to render the mixture non-flammable in air. - Gases considered effective diluents are water vapour and carbon dioxide.

5.) The use of chain-breaking inhibitors. - A recent theory suggests that inhibition of flaming of the gaseous products could be due to the influence of a suitable gaseous catalyst released by decomposition of the retardant. The catalysts usually considered are halogens and halogenated hydrocarbons.

6.) The influence of retardants that chemically affect the combustion of solid fuels. - Effective fire retardants are believed to alter the decomposition reactions (or rates of reaction) occurring in the solid[5]

7.) The influence of chemicals on glow retardance. - Various theories have been advanced in attempts to explain this phenomenon. Laboratory studies at the U.S. Forest Products Laboratories have indicated that ammonium phosphates and phosphoric acid are effective against both flaming and glowing.

Discussion

A review of literature indicated that it would be advisable to limit the present investigation to one of the seven types of retardants discussed above. It was decided to examine chemicals that intumesce or puff up on exposure to heat or flame in order to create an insulating layer over the material to be protected. Intumescent paints are known to be effective in retarding surface spread of flame (when applied to building materials), but the potential use of this type of retardant for forest fire control does not appear to have been given sufficient consideration.

Knowledge of formulations of intumescent paints is available in the literature, but paints are expensive for use solely as retardants for forest fire control. Additives that produce good paint characteristics are not necessary for the purpose under consideration, and this investigation will be directed towards developing various formulations of chemicals that produce a similar intumescent effect and in assessing their potential as fire retardants.

DEVELOPMENT OF TEST PROCEDURE

Early in the investigation it became obvious that a laboratory test would be desirable for screening possible fire retardants, although field experiments would be necessary for final assessment. Such factors as uniformity of fuel bed, moisture content of fuel and direction and speed of wind are best controlled in the laboratory.

The ideal test would be simple, would yield reliable results, differentiate the relative effectiveness of various retardants and, if possible, simulate the manner in which a retardant could be used under forest conditions.

Test Using Pine Needles

The first method used pine needles to simulate the forest floor. About 1, 500 gm of needles were placed on asbestos cement board 1 ft by 3 ft. Three different variations of this test were examined in order to establish conditions that would ensure spread of fire from one end of the bed to the other. First, the bed was inclined approximately 5 to 20 deg and the needles were ignited at the bottom of the inclined plane. This technique was used to simulate the effect of wind. Second, the bed of needles was placed horizontally and air was blown over it from one end. The fire was ignited at the leeward end so that the movement of air (about 1,000 ft per min) would spread the fire to the opposite end. Third, the bed of needles was left horizontal and a given quantity of heptane was burned in a tank adjacent to one end of the bed of needles. The fire spread from the end adjacent to the tank of heptane to the opposite end.

A measured amount of retardant was placed on 1 sq ft of the bed of needles equidistant from the ends in order to examine the suitability of the test procedure with the variations reported above. Suitability was judged on the basis of reproducibility of duplicate tests and the ability of the method to assess the effectiveness of different retardants in reducing the spread of fire. The time required for fire to advance to different positions of the bed of needles was recorded for use in assessing effectiveness. The retardants used to examine the suitability of the test method included water, a wetting agent solution and bentonite slurry.

Reliability of duplicate tests was poor. In general, fire spread by burning the needles beneath a retardant, indicating that the degree of compaction of the needles influenced the results much more than the nature of the retardant. Thus, the use of pine needles to simulate the forest floor was rejected.

Test Using Wood Fibreboard

A second method for assessing the relative effectiveness of retardants was devised. A combustible material with small variations in density was covered with retardant prior to a test. This change was made in order to overcome the problem resulting from variations in compaction of pine needles. Wood fibreboard was selected and placed in a horizontal position so that the retardant would be uniform during the test. A given quantity of heptane was burned adjacent to the substrate material to ensure spread of flame in the absence of a retardant. This technique is simpler than the alternative technique of blowing air over the substrate material during a test.

The test was set up as shown in Figure 1. One and a half gallons of heptane were floated on water in a fire tank measuring 2 by 2 by 1 ft deep. A measured quantity of fire retardant, generally in the form of an aqueous solution or suspension, was applied as evenly as possible on the wood fibreboard. Heptane was ignited and allowed to burn. As soon as it had been completely consumed the fire on the wood fibreboard was extinguished with water. The retardant was then scraped off the wood fibreboard, if necessary, to determine the length of char from the edge nearest the fire tank. Length of char was used as an index of the relative effectiveness of a retardant and was used to examine whether it provides a means for assessing relative effectiveness of retardants and yields consistent results in repeated tests.

Retardants used to examine the suitability of the test procedure included water, bentonite slurry, sodium calcium borate slurry, a wetting agent solution, a viscosity additive in water, ammonium phosphate solutions, "ABC" type dry chemical extinguishing agents and a fire retardant paint of the intumescent type.

The results indicated that this test method is not sufficiently refined for classifying fire retardant formulations in their order of effectiveness. It is of a qualitative nature and appears useful, however, in distinguishing very good and very poor retardants, as these extremes yield good repeatability. In view of the reliability of results for effective retardants, the test shows some promise for examining small differences in effectiveness of these retardants. It was, therefore, decided to conduct a series of laboratory tests on retardants after minor modifications to the test method.

DEVELOPMENT OF FIRE RETARDANT FORMULATIONS

Studies directed towards the development of fire retardants of the intumescent type were undertaken. A laboratory test, essentially the same as that developed and reported in the previous section, was selected for screening out promising retardants and examining the effect of modifying the formulations. In conjunction with this work a number of materials or formulations that have been considered as retardants or suppressants for forest fire control were examined, using the same technique in order to obtain some idea of the relative effectiveness of the new formulations.

A typical intumescent fire retardant mixture contains

1.) a blowing agent, e.g. urea,

2.) a fire retardant salt, e.g. diammonium phosphate, and

3.) a material affected by blowing agent and intumesces, e.g. glucose.

Two types of intumescent formulations were considered for the present investigation: a water solution and a dry powder. It was thought that for the water solution type the constituents of the intumescent formulations, should, if possible, be soluble in water. The application problem in the field would be simple, because equipment commonly used for application of water could be used. In addition, by attempting to develop formulations that are relatively dilute the cost of materials could be reduced. One of the requirements of the dry powder type appears to be an anti-caking property, which is important for the handling of the material in the field regardless of the method of application.

Method

The fire retardant test was set up as shown in Figure 1. Two gallons of heptane were floated on 2 in. of water in a fire tank measuring 2 by 2 by 1 ft deep. A piece of wood fibreboard, 24 by 15 by 1/2 in. thick, was positioned horizontally adjacent to one of the sides of the tank in such a manner that its upper surface was at the level of the top of the tank.

The fire retardant, generally in the form of an aqueous solution or suspension, was applied as evenly as possible over an area 24 by 12 in., leaving an unprotected strip 24 by 3 in. along the edge of the wood fibreboard farthest from the tank. The heptane was then ignited and allowed to burn until completely consumed. One observation was made to determine whether the retardant prevented ignition of the unprotected strip of wood fibreboard. If it did not ignite a further examination was made, as follows: the fire on the substrate material was extinguished with water as soon as the heptane was completely consumed. The retardant was then scraped off and the mean distance of char on the wood fibreboard, measured from the edge of the fire tank, was determined. The mean distance of char was used as the index for assessing the effectiveness of a retardant.

Retardants

The chemicals were mixed with 100 ml of water in the proportions given, except in the case of two brands of dry chemical and one brand of fire retardant paint.

Non-intumescent formulations

1) Bentonite (5 per cent)
2) Alkanol WXN (1 per cent) - a wetting agent
3) Sodium calcium borate (30 per cent)
4) Diammonium phosphate (12 per cent) + Alkanol WXN (1 per cent)
5) Monoammonium phosphate (18 per cent) + Alkanol WXN (1 per cent)
6) A commercial ABC type powder
7) Another commercial ABC type powder

Intumescent formulations

The intumescent formulations were developed by trial and error, and the quantity of chemicals used was kept slightly above the minimum required to ensure good intumescence in the present test.

1) A commercial fire retardant paint (100 gm)
2) Urea (10 gm) + diammonium phosphate (30 gm) + corn syrup (50 gm)
3) Urea (10 gm) + diammonium phosphate (30 gm) + sugar (60 gm)
4) Urea (10 gm) + diammonium phosphate (30 gm) + sugar (60 gm) + carboxymethylcellulose (2 gm)
5) Urea (10 gm) + diammonium phosphate (30 gm) + sugar (60 gm) + Keltex FF (2 gm)
6) Urea (10 gm) + diammonium phosphate (30 gm) + sugar (60 gm) + Alkanol WXN
7) Dicyandiamide (10 gm) + diammonium phosphate (30 gm) + sugar (60 gm)
8) Glycine (10 gm) + diammonium phosphate (30 gm) + sugar (60 gm)

Formulation numbers 7 and 8 were examined both in the dry state and with 100 gm of water.

Formulation numbers 2, 3, 4, 5 and 6 were of the water solution type.

RESULTS AND DISCUSSION

Intumescent formulations, in general, appeared to be more effective than the other formulations examined on the basis of the present tests. The most effective intumescent formulations appeared to be numbers 1 and 4 of the water solution type and numbers 7 and 8 of the dry powder type.

In the present experiments the quantity of retardant applied over a given area was intentionally kept to a small amount in order to exaggerate the differences in the effectiveness of retardants. Hence, the experimental results should not be construed as a positive method for screening other promising retardants. They are probably applied in greater quantity over a given area in the field than was used in the present experiments.

The water solution type of intumescent formulation did not appear to be as effective as the dry powder type, presumably because of the choice of wood fibreboard as the substrate material. Some of the solution tended to penetrate the wood fibreboard, with the result that intumescence was not as pronounced as with the powder type. Substitution of sugar for corn syrup in a formulation appeared advantageous because sugar is more readily soluble. The addition of 0.5 per cent of sodium carboxymethylcellulose (CMC) seemed to improve the retardant, while a similar addition of another viscosity additive, Keltex FF, did not show such improvement. The addition of the wetting agent, Alkanol WXN, seemed to hinder intumescence.

In order to determine the ability of a water solution type of retardant to intumesce on loosely packed materials a simple experiment was devised. The retardant was applied on a bed of pine needles and flame from a Bunsen burner was directed on the retardant-treated fuel. The results indicated that the water solution type does not intumesce sufficiently, presumably because the loss of solute into the fuel bed is too great. Solution type retardants in which increasing amounts of a viscosity additive were present were examined, but again the results were not very encouraging. The use, therefore, of this type of retardant for preparing fire lines does not seem very suitable on fuel beds such as pine needles, although there may be other forest situations where it would be successful.

A dry powder type of intumescent formulation was more effective when applied to a bed of pine needles. Its main disadvantage is the probable high cost of materials, because a relatively large quantity of powder is required. Again, it may have potential uses under certain forest conditions of which the author is not aware.

The formulation of urea, diammonium phosphate and sugar produced a powder that seemed to be hygroscopic. Laboratory examinations were carried out after grinding the chemicals to a particle size range comparable to that of dry chemical extinguishing agents on the market. The caking tendency could not be controlled by mere addition of small quantities of a water repellant material such as zinc stearate. The powder also caked when subjected to pressure in a commercial stored pressure-type dry chemical fire extinguisher so that after storage the discharge characteristics were very poor.

Attempts were made to reduce the problem created by the caking tendency of the chemicals in the formulations. Other chemicals were considered as alternatives for both sugar and urea. None of the alternatives for sugar was considered satisfactory, although both dicyandiamide and glycine showed promise as substitute materials for the blowing agent, urea. Both seemed to be less hygroscopic than urea.

The cost of a retardant or a suppressant must be considered with relation to its effectiveness before new agents can find support for wide use in forest fire control. An attempt will be made, therefore, to give some idea of the cost of the materials involved.

The main constituents of one of the powder formulations were dicyandiamide, diammonium phosphate and icing sugar. The costs of chemicals were:

Dicyandiamide	15 cents/lb
Diammonium phosphate	15 cents/lb
Icing sugar	12-1/2 cents/lb

For a powder formulation containing dicyandiamide: diammonium phosphate: icing sugar in a weight proportion of 1:3:6 the cost per pound of mixture would be about 15 cents. In the fire retardant tests carried out in the present investigation, approximately 100 gm of this formulation produced a reasonably effective intumescent retardant for protecting 2 sq ft. Thus, the cost of chemicals would be approximately 1.6 cents per sq ft or $1.60 per 100 sq ft. Actual cost for use in the forest would be considerably greater, because the above calculation was based on laboratory experiments for which the powder was applied uniformly on a flat horizontal surface. Neither the cost of producing the powder mixture nor the possible inclusion of anti-caking and free-flowing agents were considered. Prices of chemicals used in the calculation may not have been the lowest possible, but this difference may be small in relation to production cost.

In the present laboratory studies glycine appeared to be the most promising of the blowing agents examined. The formulation in which glycine is one of the constituents was not used in the calculation, however, because the price of technical grade glycine was not available to the author.

Two brands of ABC type dry chemical extinguishing agents, which have been on the market for the past few years, were examined for potential use as retardants. This type of powder is a recognized useful suppressant for extinguishing small Class A fires, defined as fires involving ordinary combustible materials such as wood and paper. The ABC type of dry chemical which was examined did not seem to depend on the property of intumescence for its effectiveness. The powder formulations that were developed appeared to be superior as retardants to the ABC type powders, according to the tests carried out in the present investigation. It is believed that efforts to develop an intumescent type dry chemical for use as a suppressant deserves serious consideration.

CONCLUSIONS AND RECOMMENDATIONS

Laboratory studies to date indicate that retardants that intumesce when subjected to fire show promise of potential use in forest fire control. Two types of such formulations suggested for consideration are:

(a) A water solution type, e. g., a retardant consisting of urea, diammonium phosphate, sugar and water. A thickening agent such as sodium carboxymethylcellulose could be added to this solution.

(b) A powder type, e. g., a retardant consisting of glycine, diammonium phosphate and sugar. Anti-caking and free-flowing agents could be added to facilitate both handling and application.

The two types of formulations suggested for consideration were found to be more effective as retardants under the conditions of test described in this report than the ABC type of dry chemical at present on the market. The powder type of formulation, if developed as a suppressant, might also have potential use for situations other than forest fire control.

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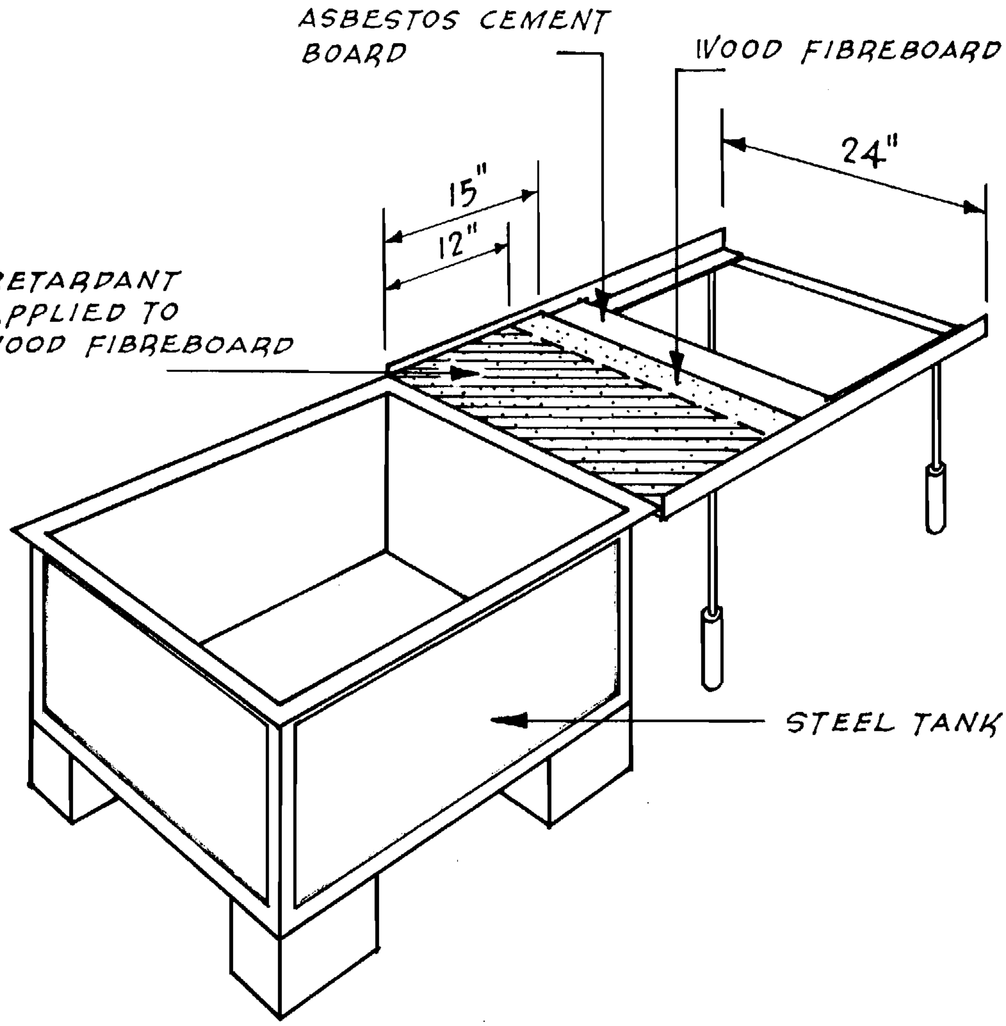

FIGURE 1

FIRE RETARDANT TEST APPARATUS

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