FIRE BEHAVIOR AND THE USE OF FIRE RETARDANTS IN CANADIAN FORESTS

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INTRODUCTION

Wildland fires continue to take their toll across Canada. Typically, fire incidence and damage vary widely from year to year according to cyclic fluctuations in weather and flammability of the fuels. In fact, the occurrence and recurrence of large fires continue as principal causes of forest renewal across the country, particularly in the lightning-fire environment of the remote and unsettled northern forest regions. In an average year, about 7,500 fires burn nearly 10,000 sq. km. of forest, tundra and grassland (Lockman, 1969), an area equivalent to a 1.5-km. wide highway extending from Newfoundland in the east to Vancouver Island in the west.

The advent of the modern era of fire control following World War II has contributed to a marked reduction of fire losses and damage, particularly in the more densely populated and intensely managed areas. However, despite the use of modern technology and expenditures in excess of $50 million annually, large-scale conflagrations continue to challenge the ability of provincial and federal fire management agencies. Although fire management comprises an integrated system involving prevention, detection, pre-suppression and suppression activities, the aerial application of water and fire retardants often represents a particularly effective and certainly the most spectacular phase of fire fighting. An estimated $5 to $10 million are expended anually on aerial attack using water and retardants.

This Symposium comprises several interrelated parts aimed at familiarizing chemists, physicists, engineers and managers with the latest developments in all aspects of flammability and fire retardants. My assigned topic suggests that my presentation should accomplish this task from a forestry perspective. Firstly, I will consider, in general terms, the effects of weather, fuel and topography on forest fire behavior. Secondly, I will discuss the application and effectiveness of commonly-used chemical fire retardants in containing and extinguishing wildland fires in northern forests, including their effects on the environment. In particular, I have tried to isolate and discuss those factors and effects which optimize the capabilities of fire retardants in different fuel and fire situations. As used in this paper, the term fire retardant refers to retardant chemicals which, when applied to forest fuels, alter the combustion process to produce less flammable products while increasing the amount of nonflammable products (George and Blakely, 1972). In

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contrast, water and water-based "short-term retardants" rely primarily on their cooling action to slow fire spread and they lose their effectiveness after the water has evaporated.

THE FOREST FIRE ENVIRONMENT

The fire environment is composed of three influences — air mass, fuels and topography — which interact to modify and control fire behavior. Of these, the air mass is the most variable, for it changes considerably from day to day as well as over relatively short distances. Meteorological processes affect all fires to some extent, but usually they have an overriding effect on the development and behavior of large conflagrations which burn for several days, weeks or even months. Topographic features, while fixed in place, are nevertheless variable from place to place and can drastically modify the behavior of a fire as it advances over the terrain. Finally, vegetation provides the thermal energy for the propagation of a fire. Some characteristics such as loading, horizontal and vertical distribution and moisture content may not change significantly over the years. However, the potential fire behavior in a particular fuel type can change drastically from one part of the fire season to another (Countryman, 1972). Variations in the moisture content of live material, its chemical composition, and the proportion of dead to live woody material within the forest are prime contributors to such seasonal fluctuations in fire potential.

The location and nature of air masses and fronts determine the weather conditions in an area. Local conditions may modify the elements of an air mass but its general characteristics remain essentially unchanged. The passage of an air mass may be accompanied by major changes in wind speed and direction, temperature and humidity; attributes usually responsible for major changes in fire weather. In addition, thunderstorms are a particularly critical element of fire weather through the fire-starting potential of lightning strikes and the erratic downdrafts which produce typically strong and gusty winds for short periods of time (Schroeder and Buck, 1970).

In the broadest sense, the climate determines the composition and extent of vegetation types which in turn comprise the fuels available for fire propagation. Within the three-dimensional structure of a vegetation type, generally predictable seasonal growth habits modify the moisture, amount, distribution and flammability of various live and dead fuel elements. Before the onset of growth in spring, the absence of lush vegetation on the forest floor and the lack of leaves on deciduous trees contribute to rapid drying and low moisture content levels of dead organic materials. Concurrently, the moisture content of conifer needles is at a minimum. In fact, the presence of highly flammable fine fuels and hot and dry fire weather often set the stage for large-scale conflagrations involving rapid fire spread through tree crowns. Following periods of prolonged drought, substantial amounts of heavy woody material lying on the forest floor and underlying organic layers become flammable, so that large, high-intensity fires may occur throughout the six-month fire season which is common in many parts of Canada.

Fire spread increases upslope and decreases downslope. Aspect and elevation influence fire behavior indirectly through their combined effects on fuel moisture and, to some extent they modify ambient weather conditions and extend a more direct influence on fire propagation through the fuel complex.

FIRE BEHAVIOR

The two risk sources, man and lightning, the number of ignition sources present, and the probability that each ignition source will produce a spreading fire if it lands on receptive fuels determine fire incidence (Deeming et al, 1974). In Canada, human activities such as smoking, recreation and debris burning account for about 75% of all fires, but these are responsible for less than one-half of the total area burned (Lockman, 1969). Identification and evaluation of individual ignition sources and their daily, weekly and seasonal distributions enables the fire manager to anticipate the location and time of man-caused fires. Lightning strikes, on the other hand, are more probabilistic in occurrence and more difficult to forecast. While no effective means of prevention has been found for lightning-caused fires, recent studies have defined relationships between lightning sensor counts, fuel moisture and lightning-fire occurrence. This approach has already contributed to improved aerial detection efficiency (Kourtz, 1974).

The presence and dryness of dead fine fuels and the extent to which these fuels are shielded by live vegetation determine the ease of ignition. Under field conditions, the upper flammability limit of most dead fuels is at about 30% moisture content (oven-dry basis), with ignition approaching certainty in the 10–15% moisture content range. Infrequently, the moisture content of fine fuels such as needle litter and cured lesser vegetation drops to less than 5%. By contrast, live foliage of Canadian conifers exhibit a seasonal cycle of moisture content, with a distinct mininum of about 75% before the new growth flushes. Such live fuels will not ignite by themselves but may be consumed if sufficient energy is generated from drier dead plant material on the forest floor. Ignition of conifer foliage occurs most often in late spring and early summer when foliage moisture content is at a minimum and the ratio of dead to live fuel components is at a maximum. Also, the absence of shade from lush green vegetation contributes to increased fuel temperatures, thereby reducing the energy required to raise these fuels to the ignition temperature of about 380°C (Deeming et al, 1974).

The rate of spread of a fire has a direct bearing on its size and shape at different times following ignition and is, therefore, a primary consideration when deciding on the appropriate suppression strategy and tactics. In the absence of wind and slope, an incipient fire will spread in a circular pattern; however, factors of the fire environment, including the continuity, condition and structure of combustibles, interact continuously to influence its shape. In most instances, a fire tends to form a head, or heads on that part of its perimeter where its intensity is greatest.

Observation and measurement of wildland fires and prescribed burns indicate that rates of forward spread range from less than 0.3 m/min for "two dimensional" surface fires to more than 107 m/min during high-intensity conflagrations where spotting of firebrands ahead of the main fire front is prominent (Kiil and Grigel, 1969; Korovin, 1969; Lawson, 1973; Van Wagner, 1973a). Spread rates of fires burning in surface fuels under forest canopies are not likely to exceed 6 m/min without the onset of crowning. Marked differences in spread rates occur, owing to fuel type variations; that is fuel condition and distribution, fuel moisture content, fuel physics and chemistry variables as well as prevailing weather conditions. Given similar burning conditions, head-fire spread in open fuels such as grass and logging slash is frequently higher than that under forest canopies, except when extreme burning conditions prevail. The initiation of fire spread through tree crowns exposes the fire to a new environment and enables it to assume an increasingly larger "three-dimensional" structure extending thousands of feet vertically. Such fires may assume storm proportions and may develop an active convection column reaching heights of 10 km or more and capable of transporting burning embers several kilometres ahead of the main fire front.

Canadian forest fire researchers commonly define fire intensity or the energy output rate per unit length of front as $I = HWR$, where I is the intensity (kcal/sec-m), H is the heat of combustion (kcal/kg), W is fuel consumed (kg/m^2) and R is rate of advance (m/sec) (Byram, 1959). By integrating the key factors determining fire behavior, this approach provides a numerical comparison of intensities of different types of fire and serves as a basis for characterizing the fire problem. It should be recognized, however, that many different combinations of fuel and weather effects can produce the same I value. Thus, other fire characteristics such as development of crown fires, spotting and convection columns should also be considered.

Documented cases of free burning fires cover a range of fire intensities from 6 to 30,000 kcal/sec-m of fire front (Van Wagner, 1968; Kiil and Grigel, 1969; Lawson, 1973; Wade and Ward, 1973). Rate of fire advance and weight of fuel consumed are the major contributors to the wide range in intensity values varying as much as 500 and 50-fold, respectively. Heat of combustion ranges from about 3800 to 5600 cal/gm and does not contribute markedly to differences in fire behavior.

In northern coniferous forests, light surface fires with a frontal intensity of about 100 kcal/sec-m of fire front can be expected to consume anywhere from 4 to 11 tons/ha of organic matter, depending on fuel type, arrangement, moisture content and weather conditions. Thin-barked trees may be killed but such fires often leave appreciable amounts of fine material on site. In British Columbia, light surface fires with energy transfer rates of less than about 80 kcal/sec-m killed practically all advance regeneration and approximately 31% of mature trees on three lodgepole pine sites (Lawson, 1973), whereas for certain eastern Canadian forests, Van Wagner (1973b) concluded that intensities less than 100 kcal/sec-m (scorch height 8 m) should kill little or no tree foliage.

Forest fire burning rates accelerate for a period of time after commencement and fire intensity may also change intermittently with a change in the fire environment. A characteristic increase in fire intensity occurs when it crowns and comes under the influence of conditions outside the stand. Under moderate to severe burning conditions, tree crowns in coniferous stands begin to burn when fire intensity ranges from about 600 to 1000 kcal/sec-m of fire front (Van Wagner, 1968; Kiil, 1975). The buildup of a fire, including the crowning phase, may last only a few minutes or several hours. Energy-output rates of sustained crown fires often exceed 5000 kcal/sec-m (Van Wagner, 1968; Wade and Ward, 1973), and such fires are often accompanied by extensive spotting, massive fire whirlwinds, buildup of a strong convection column and development of pseudo-fronts ahead of the main fire front. As a fire increases in size and intensity, it's environment extends many miles both horizontally and vertically and it will, in fact, create its own weather. Such conflagration-type fires, involving tree crowns and spreading at rates up to 6 km/hr over several hours, consume up to 50 tons/ha or more of fuel, including bark, dead wood on the forest floor, humus, tree foliage and branches. The development of heavy cumulus clouds over forest fires, followed by showers capable of containing or even suppressing such fires, has been reported by Artsybashev (1973).

Better knowledge of fire behavior is a prerequisite for improving fire prevention measures as well as upgrading detection and fire suppression strategy and tactics. Subsequently, a substantial volume of Canadian forest fire research has been concerned with the development and refinement of forest fire danger rating systems to enable fire management agencies to predict the ease of ignition, fire behavior and expected fire control requirements. The present national system, based on noon weather readings of rain, relative humidity, temperature and wind, enables the fire manager to calculate numerical codes and indices which relate to various phases of fire control planning and operations (Anon, 1970; Van Wagner, 1974). Research continues to improve its ability to reflect the variation in fire behavior among major fuel types and to provide interpretative guidelines in response to changing needs of various fire control agencies. Increasingly, system components are being used in regulating public use of forest lands, including travel restrictions and closures, to improve detection capability and dispatch procedures, and to implement fire readiness plans.

USE OF CHEMICAL FIRE RETARDANTS

Following testing and initial application in western Canada in the mid-sixties, the use of chemical fire suppressants and retardants spread eastward so that, by 1974, most provincial and territorial fire management agencies were using or experimenting with this suppression tool. Much of the total volume of about 70 million litres of water and retardants is delivered and dropped by airtankers. An estimated 15–20% of this total volume consists of chemical retardants.[1] Although the application of retardants ahead of or directly on going fires has proven to be an effective fire control tactic, the relatively high costs associated with retardants and their delivery has dictated that the capabilities and limitations of this attack mode be carefully evaluated.

Retardant Properties

The most commonly used chemical retardant mixtures are based on ammonium phosphate $(NH_4)_2\ HPO_4$ and ammonium sulphate $(NH_4)_2\ SO_4$. These materials are usually dry mixtures made up largely of the retardant and lesser amounts of thickening agents, colouring dye and corrosion inhibitor (Appendix A). The thickening agent produces a viscous slurry when mixed with water and helps to hold the liquid together during air dropping. Operational guidelines for the use of these two retardants specify viscosities in the range of 1500 to 2500 mPa.s for maintaining a thick film of retardant on the fuel. Liquid concentrates (LC), consisting of ammonium polyphosphates and other ammonium phosphates, gum or clay as a thickener and carrier for the colouring agent and a corrosion inhibitor, are also available for aerial or ground application. The presently recommended mixing ratio for this fertilizer-type solution is one part LC to four parts water, adjustable according to fuel and burning conditions.

The salt content of the retardant solution affects flammability whereas the type and concentration of the thickening agent determines, in large measure, the drop pattern distribution on the ground and the adherence of the retardant to fuels. George and Blakely (1972) concluded that a gum-thickened retardant apparently has a cohesiveness that reduces the rate of erosion and maintains a larger minimum droplet size. This phenomenon is also reflected in the lower drop times, less loss due to drift and lower evaporation losses during descent. Finally, the elastic nature of gum-thickened retardants allows the maintenance of higher effective viscosities under field conditions. Both gum and clay-thickened retardants appear to produce equivalent fuel surface coatings. Also, salt concentrations of these various retardants are set to produce roughly equivalent effects on the fire; hence, thickeners are important primarily in terms of their effect on retardant distribution patterns on the ground.

Colouring agents, one of which is the highly preferred iron oxide, are added to render the drops visible on the ground, thereby providing pilots and observers guidance for successive dropping. Both phosphates and sulphates require corrosion inhibitors to protect brass, copper and aluminum but, for best results, a mixture of different inhibitors may be required (Lyons, 1970). Since some fire retardants continue to corrode metal alloys at significant rates, extreme care must be taken to carry out regular maintenance programs on aircraft and retardant mixing equipment.

In northern latitudes especially, over-wintering retardant slurries tend to settle and they cannot easily be reconstituted to a recommended specific gravity and viscosity in the spring (Lieskovsky et al, 1974). In the case of clay-thickened retardants, the desired levels can be

[1] Phos-Chek XA and Fire-Trol 100 are two commonly-used chemical fire retardants in Canada. Tenogum is the most popular short-term retardant.

reached with the addition of clay or salt, but repeated adjustments continually increase the volume of residual slurry on the bottom of the tank.

Delivery Systems

Fixed-wing airtankers, usually of World War II vintage, are commonly used to deliver retardants to fires. The application of water and retardants by helitankers is increasing, but this method of retardant delivery still accounts for a very small portion of the total volume used. Ground application of retardants has considerable potential near populated centres where good road access is available.

Land-based airtankers such as the TBM Avenger (2270 l.), B-26 (4080 l.) S2F Tracker (3630 l.) and DC-6B (10,890 l.) exemplify the type and capacity of retardant-delivery aircraft. In regions where water is easily available, amphibious Otters (680 l.), PBY Cansos (3630 l.) and CL-215's (5450 l.) are used for skimming over lakes for water pick-up delivery. The CL-215 is the only aircraft designed specifically as an airtanker and has the capability of being used in both land-based and water-based operations. In contrast to airtankers, helicopters generally employ an external tank or a slinging bucket suspended from the cargo hook. Medium-sized helicopters with 1100 to 1600 l. capacities appear to be more desirable than larger or smaller capacity machines in that production rates and costs are optimized (Simard and Forster, 1972).

The effective use of airtankers is facilitated by maintenance of diverse retardant mixing, handling and storage bases. The larger permanent bases consist of several storage tanks in the 45,000 to 90,000 l. capacity range, with a mixer for handling 135,000 l/hr (Anon, 1974). More commonly, moderate retardant demand is satisfied by a mixer producing 55,000 l/hr. Loading of mixed retardants aboard airtankers is accomplished by high volume pumps in the 1800 l/min range and multiple loading stations. Areas of low or cyclic demand for retardant are increasingly handled by portable mixers at mobile bases. In some instances, where helicopters are used, portable mixers are airlifted and set up adjacent to a fire to increase retardant volume delivery by helitankers (Grigel, 1974).

The efficient aerial cascading of retardants is determined partly by the flow rate from the tank, the tank-opening rate, tank geometry, venting and door area (Swanson et al, 1975). The distribution of the retardant in the pattern can be modified by the selection of aircraft drop height, velocity, and angle of attack. Since most aircraft carry several tanks, the drop pattern on the ground can be controlled by using one or more tanks with different time intervals between tank releases. As expected, control of door openings provides the pilot with the additional capability to modify the ground pattern and coverage levels within the pattern. It is likely that the effectiveness of conventional cascading methods of retardant delivery can be improved by continued design, testing and integration of system components.

In recent years, a Modular Airborne Fire-Fighting System (MAFFS) has been developed whereby five 1900 l. tanks are installed in a Hercules C-130 or similar cargo aircraft (Peterson, 1974). Probably the most outstanding feature of the system is the pressure ranging from 69 to 276 kPa which provides the power to force the retardant out of the tanks to produce a relatively long and narrow drop pattern. However, this system is expensive and unlikely to replace conventional gravity-dependent retardant dropping systems in the foreseeable future.

Retardant Distribution Patterns

The amount of retardant recovered on the ground reflects the efficiency of the aircraft tank and gating systems, the effectiveness of thickening agents to produce the desired retardant coverage and concentration, and the ability of the vegetation to intercept and retain part of the drop. The shape of a retardant drop is influenced by such things as aircraft height and speed, wind speed, the retardant release sequence, the size of the load and the type of retardant. Based on the assumption that 0.8 l/sq. m. represents adequate coverage, the commonly-used airtankers such as the TBM, the B-26, PBY Canso and the CL-215 can build anywhere from 50 to 500 m. of fire-line. Conventional "free-fall" application from a 30 m. height can be expected to produce from 2.1 to 3.6 centimetres of line per litre carried, with the pressurized MAFFS likely to achieve 4.2 centimetres of line per litre (Anon, 1973).

Drop height becomes increasingly critical when higher concentrations of retardant are required to retard or extinguish a fire, with a 50 m. height producing the maximum length and area coverage of fireline. Higher drop heights are likely to produce greater length and area coverage of the fire-line at lower retardant concentrations (Anon, 1973a). At lower drop heights, recovery of gum-thickened retardants exceeds that of clay-thickened products and water by about 10%. The difference in recovery rates increases with drop height, with the greatest real difference between gum-thickened retardants and all others evaluated (Anon, 1973b; George and Blakely, 1973).

Results of numerous air drop tests in open fields suggest that over 80% of a drop will likely reach the ground. In forested areas, the tree canopy intercepts and retains part of the drop, thereby the amount reaching the forest-floor surface is further reduced. Theoretical and empirical studies (Grigel, 1971; Anderson, 1974) provide useful insight into retardant retention and distribution in relation to different species and timber types, but additional information will be required before the optimum distribution of retardant in a variety of fuel, fire and retardant application modes can be reliably predicted. Well-stocked stands of lodgepole pine and white spruce-aspen in Alberta retain as much as two-thirds of the retardant in the tree canopy. While the high retention rate undoubtedly has a marked effect on the spread of a crown-fire, the type of retardant distribution and its uniformity on other critical fuels controlling fire propagation also need to be quantified. Multiple drops involving different retardant viscosities may be required to optimize canopy penetration and adequate coating of critical fuels such as crown foliage and litter on the forest floor.

Retardant Effectiveness

Using a method developed for testing of fire retardant chemicals, Johansen (1967) concluded that ammonium sulphate is about two-thirds as effective as ammonium phosphate in reducing the flammability[2] of fuels. This is reflected in the recommended use levels which have been developed over many years of field application for these two retardant solutions: the ammonium sulphate chemical salt content is 50% higher than for the ammonium phosphate chemical to achieve equivalence in field effectiveness (Appendix A).

The differences in the effects of ammonium phosphate and ammonium sulphate are greater on glowing combustion than on flaming combustion. George and Blakely (1972) showed that ammonium sulphate had completely decomposed by about 425°C while ammonium phosphate decomposed at about 675°C. It is likely that little or no ammonium sulphate remained by the time the fire front had passed, whereas some ammonium phosphate might still have been present. Thus, the duration of a particular temperature level in the combustion zone would influence the amount of chemical available and its effect on glowing combustion.

Chemical retardants alter the chemistry of the preheating stage of burning by changing the

[2] Flammability is defined as the interaction of ignitability, sustainability and combustibility (Anderson, 1970).

fuel to carbon and water rather than to combustible gases and ash (Handleman, 1971). Depending on the application rate and ambient weather conditions, the common retardant types dry at about the same rate and are likely to lose more than 90% of their initial moisture within 4 to 8 hours. Under laboratory conditions, a loss of 2/3 of the moisture in a retardant solution still resulted in a rate of spread less than one-fifth of that in an untreated fuel bed (Rothermel and Hardy, 1965). By comparison, short-term retardants remain effective only when the moisture retained around or in the fuel is at least 22% of the oven-dry weight of the fuel. Thus, chemical retardants remain effective well below the value which might be expected if moisture alone were causing the reduction in rate of spread.

For retardants such as Fire-Trol and Phos-Chek, between 0.8 and 1.6 l/sq. m. are required to stop fires of varying intensities in different fuel types (Anon, 1967). Although retardants are more effective extinguishing agents than water, even a low-intensity fire generating about 100 kcal/sec-m of fire front requires a minimum of 0.8 l/sq. m. of water (Stechishen and Little, 1971). Quantitative information about the amount of retardant required for effective control of higher-intensity fires in logging slash and northern conifers is not available, but treatment levels appreciably in excess of 2 l/sq. m. are not considered unrealistic. In relation to drop pattern distributions and the relatively small areas of retardant concentrations in excess of 2.0 l/sq. m., repeated drops on the same fuels are sometimes essential. Fire containment thus depends on the ability of the airtanker to lay a retardant line of the desired coverage level at a rate in excess of the spread rate of the fire.

Recent work by Swanson (1973), Swanson and Helvig (1973) and Swanson, et al, (1975) has resulted in the development of a model for predicting retardant requirements for various fuel and fire situations. The model estimates the reduction in fire intensity over a range of retardant concentrations and fuel types. An interesting aspect of the model relates to the concept of maximum useful retardant concentration (Rothermel and Philpot, 1974), which has subsequently been developed to incorporate a measure of the required retardant film thickness needed to stop a fire. For the 11 fuel models used in the study, the values of the maximum useful retardant concentration ranged from 0.3 to 3.9 l/sq. m. (Swanson, et al, 1975). Although the retardant prediction model appears to be sensitive to differences in fire intensity as represented by the fuel models, additional information will be required on retardant effectiveness in northern fuel types and using different application modes.

Ecological Impact of Fire Retardants

Normal application of fire retardants can be expected to have no more than a localized fertilizing effect on various terrestrial plant species. Nitrogen concentrations in a range of 25 to 75 kg spread unevenly over a drop area of one-fifth of a hectare can be expected, but this level of fertilizer generally produces beneficial effects on site productivity. Observation of vegetative growth on an open site in Alberta following repeated retardant drops reflects the generally salutary effect of chemical retardants on forest vegetation.

Retardants appear to have their greatest ecological impact on aquatic ecosystems, with numerous fish kills being reported (McKee and Wolf, 1963; Douglas, 1974). Blahm et al (1972) examined the effects of Phos-Chek and Fire-Trol retardants on juvenile coho salmon and juvenile rainbow trout and concluded that fire retardant compounds are toxic to fish. They also recognized the profound effect that pH of the environmental water has on the toxicity of the retardants and noted the possible toxic effects of chemical constituents other than ammonia. Artificial addition of nutrients such as phosphorous and nitrogen to lakes is known to stimulate algae growth and

APPENDIX A

1974 FLAME INHIBITING (long-term) RETARDANT CHEMICALS IN USE IN CANADA

As adapted from various sources by the NORTHERN FOREST RESEARCH CENTRE – CANADIAN FORESTRY SERVICE, EDMONTON, ALBERTA

BRAND NAME	COMPOSITION	PERCENT	MIXING RATIO lb/gal water	MIXING RATIO lb/gal soln	MIXED DENSITY lb/gal	VISCOSITY IN CENTIPOISES	SALT CONTENT % by weight in soln	SWELLAGE % BY VOLUME	GAL. SOLN PRODUCED per ton of dry chem/ton	PACKAGING METHOD	MIXING PROCEDURE	APPLICATION METHOD	STORAGE PROCEDURE	1974 COST 22 TON MINIMUM	REMARKS
PHOS-CHEK XA	$(NH_4)_2HPO_4$ DIAMMONIUM PHOSPHATE (ORTHO 21-53-0) GUAR GUM THICKENER IRON OXIDE COLOURING CORROSION AND SPOILAGE INHIBITORS	89 8 1 2	1·37	1·28	10·6	1500-2000	10·6 DAP 5·7 P_2O_5 equivalent	7	1500 (1180 @ 7·5% P_2O_5 equivalent) ①	- 57 lb. bags - 1 ton pallets - bulk	continuous flow eductor - batch	aerial	- wet - dry	$420.00/ton	(a) Inhibits glowing and flaming comb. Incorporates most superior (b) fire retardant chemical Readily mixed Quality control readily maintained Corrosion inhibited for aluminum, copper and ferrous alloys, and magnesium Good cohesive properties Viscous solution One-bag product 90-Day wet storage guarantee
PHOS-CHEK 259	AS IN XA ABOVE	94 2 1 3	1·92	1·75	10·9	50-100	15·0 DAP 8·1 P_2O_5 equivalent	0	1140	50 lb. bags	- continuous flow eductor - batch - agitation	ground	- primarily dry	$420.00/ton	Low viscosity for ease of pumping for ground application Higher active salt content than XA a.b.
FIRE-TROL 100	$(NH_4)_2SO_4$ AMMONIUM SULPHATE (21-0-0) ATTAPULGITE CLAY THICKENER IRON OXIDE COLOURING CORROSION INHIBITOR	63·5 35 1 ·5	3·34	2·78	11·3	1800-2300	15·6 $(NH_4)_2SO_4$	20	720	50 lb. bags - batch		aerial	- primarily wet	$159.00/ton	Viscous slurry Ammonium sulphate only 2/3 as effective as ammonium phosphate Primarily effective in retarding flaming combustion Economical, but logistically inconvenient One-bag or 3-bag product Mixing procedure slow Mixer horsepower and mixing time critical Abrasive when in motion Sodium dichromate inhibits aluminum 2024 T3 corrosion
FIRE-TROL 931	$(NH_4)_2HPO_4$ DIAMMONIUM PHOSPHATE (POLY N 10-34-0 liquid fertilizer) ATTAPULGITE CLAY COLOUR CARRIER AND THICKENER IRON OXIDE COLOURING CORROSION INHIBITOR	93 4 2 1	3·70 @ 4:1 RATIO	2·96 @ 4:1 RATIO	11·0 @ 4:1 RATIO	50-150	15·4 DAP 8·3 P_2O_5 equivalent	0	675 (14·8 lb/gal)	- 670 lb/45 gal - bulk	- proportioner (blending) - agitation	aerial	- concentrate only	$177.00/ton	Non-viscous solution Minimal and ease of handling VARIBLENDER provides improved control of LC and water intake New improved corrosion inhibitor Solution mixed upon discharge from loading pump Polyphosphate reverts to orthophosphate during long term (1) storage of LC 8·3% P_2O_5 in 10-34-0 is equivalent to 7·5% P_2O_5 in reagent grade DAP In-line thickening agent may be available a.b.
FIRE-TROL 934	DIAMMONIUM PHOSPHATE (POLY N 10-34-0) CORROSION INHIBITOR	98·7 1·3	3·70 @ 4:1 RATIO	2·96 @ 4:1 RATIO	11·0 @ 4:1 RATIO	50-60	15·8 DAP 8·5 P_2O_5 equivalent	0	675 (14·8 lb/gal)	- 670 lb/45 gal - bulk	- proportioner - agitation	ground	- concentrate only	$177.00/ton	Similar to FT-931 but: - no clay content - non-abrasive - colourless a.b.c.
rgn 72-74															

From Grigel (1974)

*Information noted a, b, c, etc. applies to all products so marked may contribute to a subsequent drop in oxygen concentrations.

In addition to the amount of retardant entering a stream, the magnitude and duration of toxic exposure to aquatic organisms differs according to the surface area, depth and flow characteristics of the body of water. Van Meter and Hardy (1971) developed a computational system for estimating the zone of the stream in which damage to fish might be expected at different times following contamination.

CONCLUSIONS

Depending on weather, fuel and topographic conditions, fire intensity fluctuates widely, with 5000-fold increases possible. While the concept of fire intensity provides a meaningful quantification of fire behavior, continuously varying combinations of burning conditions may produce the same or similar intensity ratings, thereby limiting their usefulness as a decision-making aid in fire management. Additional studies are required to facilitate the development of a comprehensive fire danger rating system, but equally important is the need to modify and to implement key numerical and descriptive indicators at a level of sophistication commensurate with the needs of fire management agencies to use these tools in improving the planning and operational phases of fire attack systems.

Recent research on retardant delivery systems, retardant properties and application modes has facilitated the development of user guidelines for optimizing retardant effectiveness in different fuel and fire situations. Models are available for predicting retardant requirements but these need to be tested under field conditions. In particular, field assessments are required to quantify the effectiveness of retardants and water in direct and indirect application modes. Similarly, the horizontal and vertical distribution and concentration of retardant in key fuel complexes needs to be known. Finally, cost/benefit ratios for different airtanker-retardant combinations will enable the fire manager to assess and select the best attack system to optimize suppression effectiveness and to minimize damage to the forest resource.

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