COST-EFFECTIVENESS OF THREE GROUND-TANKER SYSTEMS

by
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FOREST FIRE RESEARCH INSTITUTE
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I N D E X

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APPENDICES

I. INTRODUCTION

1. The Purposes of the Study

This study was designed for two purposes: to compare retardants in a way that is relevant to decisions required of fire-control managers, and to provide chemists working on high-expansion foams with some idea of its present field effectiveness.

To satisfy this dual purpose, the main text is brief but detail on methods and results is documented in appendices.

The scope of this study is limited - only three retardants were tested on backing fires for one set of fuel and weather conditions. To compensate for this limitation, several of the references on retardant effectiveness have been abstracted in the Bibliography.

2. How Fire-Control Managers use Ground-Tankers

The fire-control manager has essentially two uses of a ground-tanker:

a) to establish temporary control lines,

b) to reduce fire rate of spread.

In prescribed burns, chemicals have been applied to particularly hazardous areas such as boundaries between slash and timber, to reduce fire intensity at these points to a more manageable level. Greater concentrations of chemicals will fireproof the fuel, thus providing the manager with a method of constructing control lines so that he can burn in any block size. In forest-fire suppression the objective is invariably to construct a line that completely retards fire spread, and fireproofs the treated fuel for at least 20 to 30 minutes.

In areas of water scarcity and good accessibility, ground tankers can be used as a substitute for lengthy hose-lays. The excellent mobility of 4-wheel-drive vehicles carrying small slip-on tankers has made them popular even where short hose-lays are possible. Field experience has shown that expert application of small amounts of chemical solution is less costly and just as effective as massive but indiscriminately placed amounts.

1. A Criterion for Comparing Ground-Tankers

Whether on prescribed burns or going fires, whether the objective is partial reduction of fire intensity or complete, the same concept of tanker effectiveness applies: for a given transport vehicle, the most effective system is the one that fireproofs the greatest area of fuel to a prescribed level.

Consider the following comparison between tanker systems A and B:

Prescribed Fireproofing Level	Area of Fuel that can be treated by A (one load)	Area of Fuel that can be treated by B (one load)
1. Reduction of original rate of spread by 75%	5,000 sq.ft.	4,000 sq.ft.
2. Retards fire spread completely, fuel won't ignite for 30 minutes	2,600 sq.ft.	2,000 sq.ft.

Now if the two systems cost the same, then system A is preferred to system B.

Cost cannot be handled in a straightforward manner in the criterion. Capital costs and operating costs of a system are important but may be less important than the following considerations:

a. System dependability,
b. training required to use a system,
c. crew safety - many retardants are extremely slippery,
d. problems in the storage of chemicals and maintenance of equipment.

These and other considerations have been thoroughly reviewed in the N.F.P.A. Forest Committee publication "Chemicals for forest fire fighting", 2nd edition, N.F.P.A. Assn., 60 Batterymarch Street, Boston, Mass. 02110. pp. 106, illus., photos. ($3.00 per copy).

II. LABORATORY AND FIELD TEST PROCEDURES

Although many desirable properties of a retardant could be specified and tested, both laboratory and field tests were restricted to determining the weights of chemical required per square foot of fuel to achieve a specified level of fireproofing.

A lab test fire was used to compare the effectiveness of both water and viscous retardant on a pine needle fuel bed. This test-fire procedure is identical to that used by Mr. C.E. Van Wagner in his investigation of the mechanisms of fire spread in litter fuels. The results of retardant treatments on this test-fire are considered representative of backing surface fires in Red Pine litter. Details of the lab test-fire procedure are in Appendix I.

A field test-fire procedure was designed to estimate the comparative fireproofing effectiveness of retardants in a balsam-fir slash fuel, loaded at a rate of 15 tons per acre. The increased realism of the field test-fire was offset by the disadvantage of more costly fuel material. Gusts of wind during the test-fires caused greater fluctuations in fire behaviour than was observed in the lab.

To ensure a consistent moisture content, slash was stored in a drying shed for 2 months. Slash for each 2 ft. x 10 ft. test-fire was then carefully weighed before being placed on the test-fire strips.

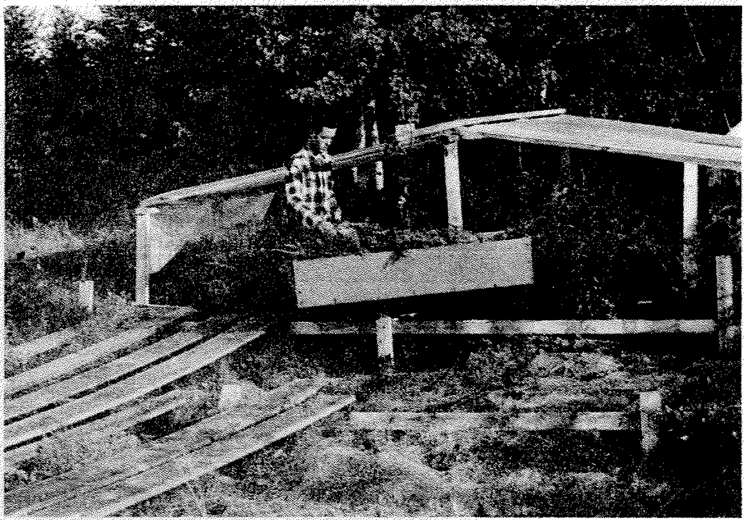


Photo 1. Weighing fuel samples for test strips. The fuel shelter is in the background.

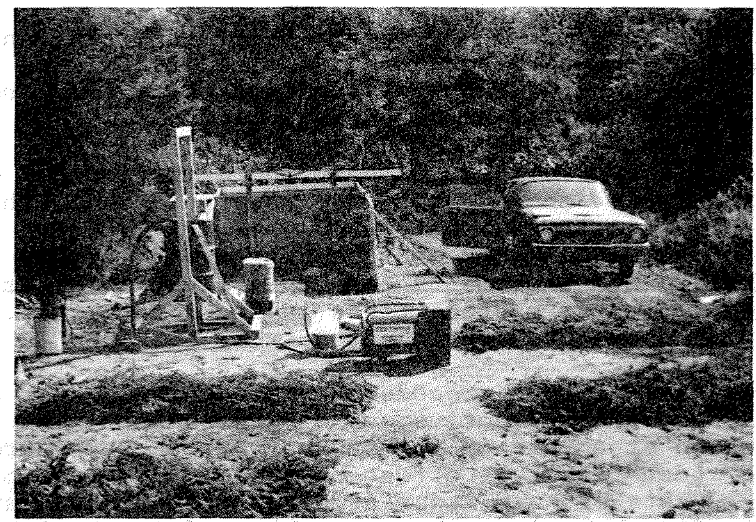


Photo 2. Arrangement of test-fire strips. A Bliss-Rockwood foam generator is in the centre and the arrangement for weighing the amount of water used is immediately behind it.

Each test-fire strip was divided into a control portion and a treated portion. After a weighed amount of retardant was applied to the treated portion, the front edge of the control portion was ignited.

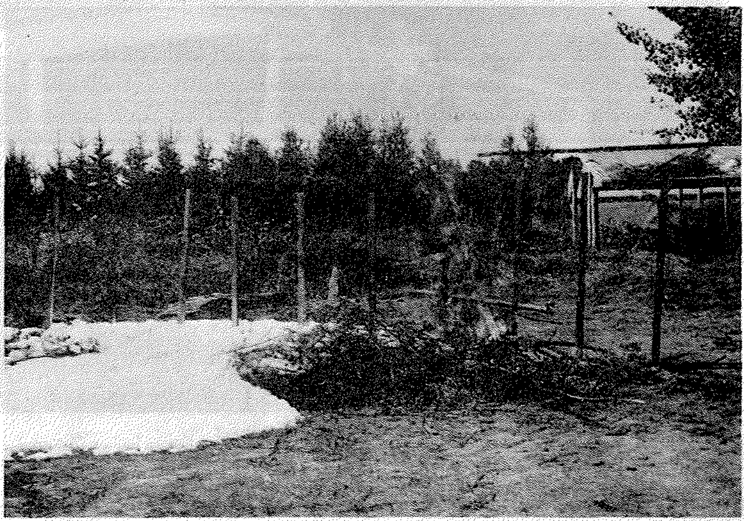


Photo 3. Test fire advancing on the control portion to the portion treated with high-expansion foam. The aluminum stakes are set at 1-foot intervals.

Rate of spread was measured in the control and treated portions by timing the advance of the burning edge between successive stakes with a stop-watch. Additional detail of the field test-fire procedure is in Appendix II. Water and viscous-water were weighed and applied with a sprinkling apparatus as a fine spray. Foam treatments were considerably more difficult to apply. It was necessary to generate several samples of foam so that, for each foam generator and foaming agent injector setting, foam expansion could be estimated. The results of 5 foam expansion tests are in Appendix III.

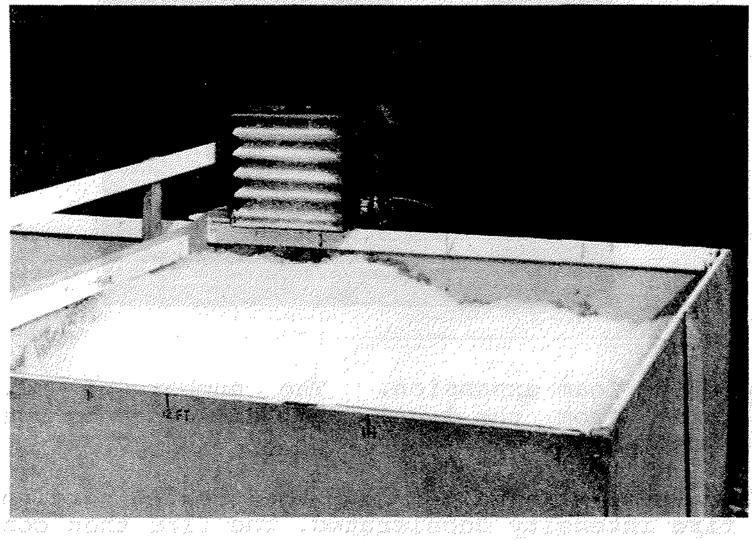


Photo 4. Foam sample generated with a Bliss-Rockwood foam generator. Total foam volume from a weighed amount of water and foaming agent can be measured in the hardboard expansion chamber.

To determine the weight of foam applied to each test strip, foam depth and foam expansion were measured.

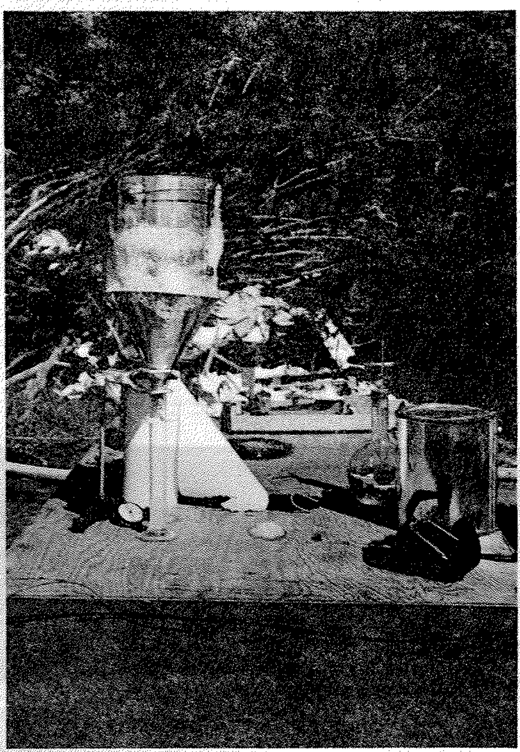


Photo 5. Measuring foam expansion. The number of ml. of solution draining from the 1-gal. sample of foam is used to calculate foam expansion.

As the burning edge advanced into the treated portion the rate of advance and fire intensity decelerated. The fire then continued to burn at a new equilibrium or it went out altogether.

If the fire continued at a new equilibrium, the fireproofing effectiveness of the treatment was calculated with the following formula:

$$1.0 \quad \frac{ROSC - ROST}{ROSC} \times 100 = \text{Percent reduction in rate of spread}$$

'ROSC' is the rate of spread in feet per minute on the control portion of the test fire; 'ROST' is the rate of spread in the treated portion. In addition to the above measure, the percent reduction in fire intensity can be estimated with formula 2.0.

$$2.0 \quad I = H \times W \times R$$

Since 'H', the specific heat of wood, is constant at 7,000 Btu. per pound of fuel at 10 percent moisture content, and 'W', the weight of wood fuel burned, is constant at .7 lb. of fuel per square foot since combustion was complete, this formula can be simplified to formula 2.1, where 'R' is rate of spread in feet per minute.

$$2.1 \quad I = 4{,}900 \times R$$

The percentage change in fire intensity from the control to the treated portion of the test-fire can be calculated as,

$$3.0 \quad \frac{4900 \times ROSC - 4900 \times ROST}{4900 \times ROSC} \times 100$$

Formula 3.0 can be easily simplified to,

$$3.1 \quad \frac{ROSC - ROST}{ROSC} \times 100$$

which is the same formula as that for calculating the percentage change in rate of spread.

If the fire was stopped completely by the treatment, then the time before the fuel would reignite was recorded as a measure of retardant duration.

III. ANALYSIS OF TREATMENTS

Field tests of high-expansion foams, at this early stage in their development, can only serve as a milestone that indicates how close they have come to a type that could be considered adequate for forestry purposes. Viscous retardants have had a comparatively long history of development and application.

Comparative data on the weight of retardants required to achieve a given level of fireproofing are given in Table 1 below:

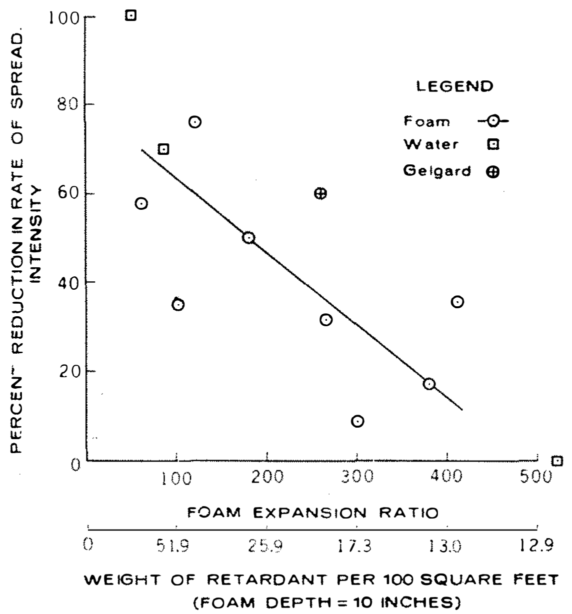
Table 1. Weights of retardant per 100 square feet of test fuel for two levels of fireproofing effectiveness.

	Fireproofing Level	Water	Viscous-Water	Foam
1.	60 Percent Reduction in Rate of Spread	50 lb.	20 lb.	40 lb.
2.	30-minute fireproofing	100 lb.	60 lb.	-

1. The Foam Treatment

Foam expansion appears to have an important bearing on its fire-retarding effectiveness, but as can be seen from the 2 x-axes in the graph below, this property is confounded with the weight of solution in the treatment.

FIGURE I
PERCENT REDUCTION IN TEST FIRE RATE OF SPREAD, VERSUS WEIGHT OF RETARDANT PER 100 SQUARE FEET.



To obtain foam expansions from 100:1 to 400:1, a Jet-X Nozzle was used for the lower range of expansions, and a Bliss-RockwoodModel-2 for the higher.

Higher expansion foams failed to penetrate the test-fire strips completely, and the fire continued to burn beneath it. The best results were obtained with a 100:1 expansion foam (see photos below).

Photo 6. Flame height in the control portion of the test strip. Rate of spread is about 2.4 f.p.m.

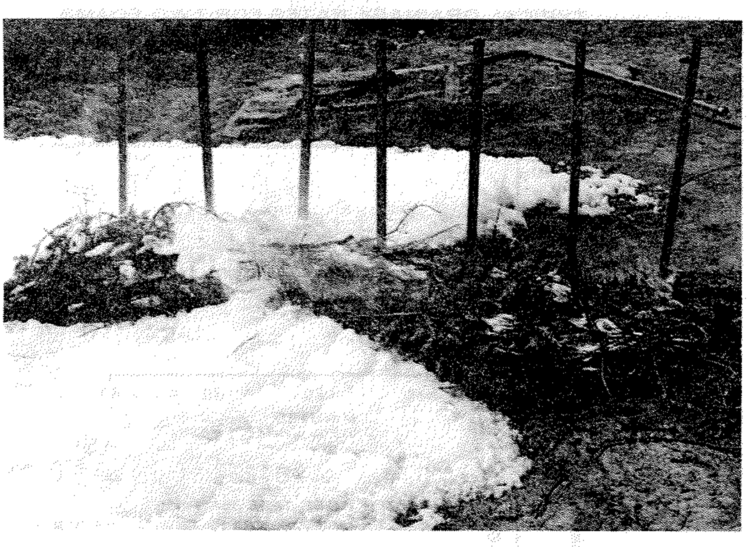


Photo 7. Flame height and fire intensity is greatly reduced in the treated portion of the test strip. Rate of spread has been reduced by 70%, but the foam is dissipating in front of the burning edge.

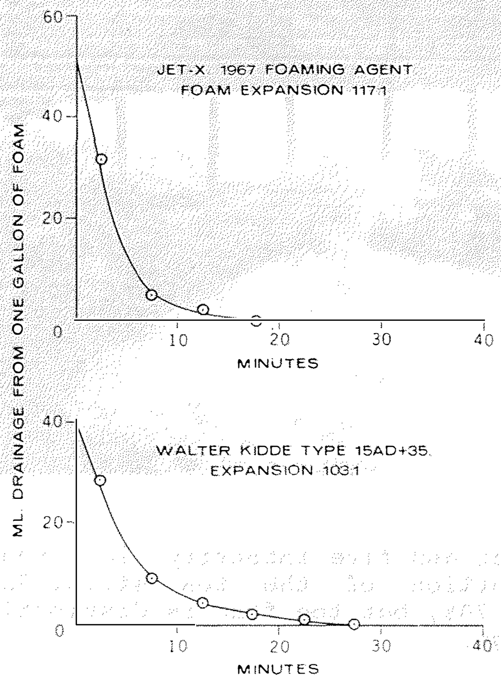
As can be seen in the photograph above, foam stability - conventionally measured as the rate of volume collapse of a foam sample - is an important property of foam when it is used as a retardant. The terms "persistence" and "duration" are usually considered synonymous with foam "stability". Stability properties of a foam, as measured at room temperature and humidity, are believed to be an indication of its stability in high temperatures, low humidities, and after a fire has been lit next to it - heat radiation from 10 to 30 thousand Btu. for about one minute. At least one research chemist has developed a direct method of measuring a foam's heat-resistant properties (P.H. Thomas, 1959).

Another important property of high-expansion foam is its drainage rate. Drainage rate is the rate at which solution drains from a foam sample. Theoretically, drainage rates from foam should not exceed the fuel's capacity for adsorbing water from a film of free water, since the excess would be wasted.

To estimate the rate at which fine fuels (1/4 inch diameter) could adsorb moisture, a foliage sample was taken immediately before the application of foa , and again 20 minutes after. The moisture increase was from about 10 percent of dry weight to 25. Larger diameter fuels did not increase in moisture content and it was precisely these fuels which carried the fire. Since most forest fuels will continue to burn below a 25% moisture content, the heat-absorbing and heat-reflecting qualities of the foam must be developed for the additional retardant action needed.

The graphs below illustrate the drainage rates from two commercially available high-expansion foams.

FIGURE II
TYPICAL DRAINAGE RATES FOR TWO FOAMS



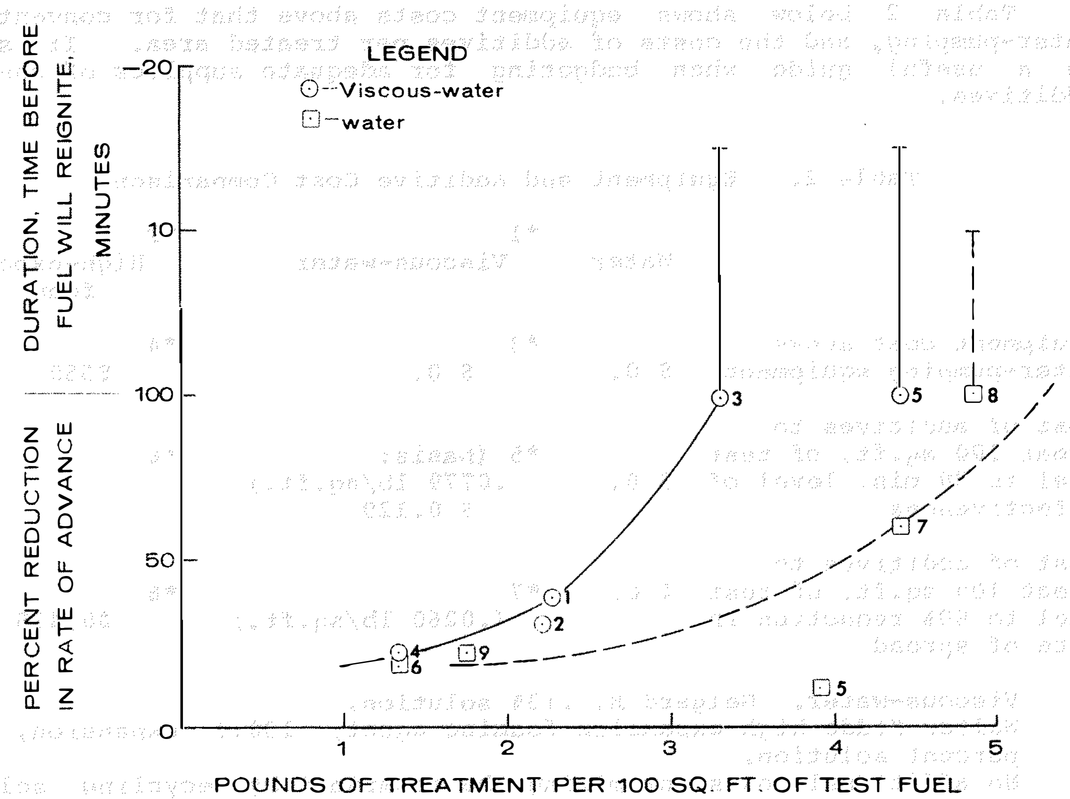
2. The Water and Viscous-water Treatments

A comparison of water and viscous-water treatments is given in Table 1 of the last section. Since both of these treatments were applied as an even, find spray, the weights given must be considered the minimum that could be achieved in operational conditions.

Further comparisons of viscous-water in a test fuel of Red Pine litter shows that the comparative advantage of a viscous retardant increased with the required level of fireproofing.

FIGURE III

COMPARISON OF THE FIRE RETARDING EFFECTIVENESS OF VISCOUS-WATER AND WATER IN A RED PINE LITTER TEST FUEL



Complete data on this test-fire series is given in Appendix I.

IV. COMPARATIVE COSTS AND EFFECTIVENESS OF THE THREE SYSTEMS

At the outset of this comparison, the severe restructions on interpretation of the following tabular data will be explained:

1. The effectiveness data is an approximation to results that would be obtained for backing fires in 15 tons per acre fuel, wind 0-5 m.p.h., fuel moisture content 10-14 percent.

2. The number of replications of each treatment are too few to permit statistical analysis of effectiveness measures. Emphasis was placed on the quality of the test fires and the exactness of the treatment rather than on number.

3. Since both the water and viscous-water treatments were applied slowly as a spray and more carefully than is possible under operational conditions, weights of retardant per 100 sq. ft. listed in the following tables must be regarded as a numinum rather than an operationally attainable average.

Table 2 below shows equipment costs above that for conventional water-pumping, and the costs of additives per treated area. It should be a useful guide when budgeting for adequate supplies of chemical additives.

Table 2. Equipment and Additive Cost Comparison

	Water	*1 Viscous-water	*2 High-expansion foam
Equipment cost above water-pumping equipment	$ 0.	*3 $ 0.	*4 $550
Cost of additives to treat 100 sq.ft. of test fuel to 30 min. level of effectiveness	$ 0.	*5 (basis: .0779 lb/sq.ft.) $ 0.129	*6
Cost of additives to treat 100 sq.ft. of test fuel to 60% reduction in rate of spread	$ 0.	*7 (.0260 lb/sq.ft.)	*8 $0.415

1. Viscous-water. Gelgard M, .13% solution.
2. Walter Kidde high-expansion foaming agent, 100:1 expansion, 1.40 percent solution.
3. No additional costs for mixing the retardant by recycling solution through the pump.
4. Approximate cost of a foam generator assembly.
5. Basis: 60 lb. Gelgard per 100 sq.ft., .13% solution, $1.66/lb. F.O.B.
6. This level could not be achieved in tests.
7. Basis: 20 lb. Gelgard per 100 sq.ft., .13% solution, $1.66/lb. F.O.B.
8. Basis: Foam expansion 120:1, foam depth 10", 1.39% foaming agent in solution, 43.24 lb. of foaming agent/100 sq.ft. Cost $.70/lb.

While the preceding table gives an indication of costs, an additional step is required to answer the vital question 'How many hundreds of square feet can I treat with one tank-load?'

Take the case of the water-tanker system which has a maximum load of 3,000 lbs. (300 gal.). The viscous-water payload would be 2,950 lbs. for the foam generator system because of foam generator weight.

Fuel area that can be treated with one tankload follows directly by calculating: $\frac{\text{Payload weight}}{\text{Weight required per 100 sq.ft.}}$

Table 3. Areas that can be fireproofed with a tank load of water, viscous-water, and foam. Retardant costs are included.

	Water	Viscous-water	Foam
Maximum payload in lb. if max. water load is 3,000 lbs.	3,000 lb.	2,950 lb.	2,950 lb.
Sq.ft. of test-fuel that can be treated to 60% reduction in rate of spread	*1 6,000 sq.ft.	*2 14,750 sq.ft.	*3 6,822 sq.ft.
Cost of chemicals per 100 sq.ft.	$ 0.0	$ 0.043	$0.415
Sq.ft. of test-fuel that can be fire-proofed for 30 min.	*4 3,000 sq.ft.	*5 4,833 sq.ft.	*6 --
Cost of chemicals	$ 0.0	$ 0.129	--

1. Basis: .5 lb. water/sq.ft.
2. Basis: .20 lb./sq.ft.
3. Basis: .422 lb./sq.ft.
4. Basis: 1 lb./sq/ft.
5. Basis: .60 lb./sq.ft.
6. Not attained with foam treatments.

V. CONCLUSIONS

These tests indicate, on the basis of "Minimum weight per 100 sq. ft. for specified retarding effectiveness", that a viscous-water tanker system is preferred.

Treat this conclusion with caution. Foams of greater stability and fire-retarding properties are being developed. Skilled operators are required to realize the full advantages of viscous-water retardants.

BIBLIOGRAPHY AND ABSTRACTS

1. General Reviews

Anon. Foam - How it's used and how it's made. FPA Journal, Vol. 69, p. 159-165.

Godwin, D.D. 1936. Aerial and chemical aids. Fire Control Notes, Dec. 1936, p.11.

A back-pack "foam rig" was 8 times more effective than an equivalent amount of water for suppressing small fires. Sodium bicarbonate and aluminum sulphate reacted chemically in presence of bubble forming and fire retarding additives to produce a chemical foam.

Lowden, M.S. 1962. Forest fire-fighting retardants in the U.S. Woodlands Review, April 1962.

An excellent comparison of fire retarding chemicals and methods for their application, by the Director, Division of Fire Control of the U.S. Forest Service, Washington, D.C.

N.F.P.A. Forest Committee. 1967. Chemicals for forest fire fighting. National Fire Protection Ass'n., 2nd edition, 60 Batterymarch Street, Boston, Mass. 02110. pp. 106, illus., photos. ($3.00 per copy).

This report is the most comprehensive available on all aspects of research and use of fire fighting chemicals.

Sumi, K. 1963. Forest Fire Retardants. N.R.C. Division of Building Research. Internal Report No. 274, May 1963.

2. Retardant and Suppression Theory

Aquadyne Corp. (not dated). Aquadyne: The theory of wet water, including the mathematics of multi-phase "wetting". 10 pp., illustrated.

Canadian Wood Council. 1966. Wood fire behaviour and fire retardant treatments; a review of the literature. Ottawa, the Council, 1966. 175 pp., tables.

De Gaeta, P.F. and A.A. Weintraub. 1957, 1958. Theory and application of wet water. Fire Engineering 110 (8): 790-791; 883-885; 110 (12): 1208-1210, 1234-1236; 111 (4): 288-290; 111 (5): 380-381.

Rothermel, R.C. and C.E. Hardy. 1965. Influence of moisture on effectiveness of fire retardants. Ogden I.M.F.RiES. 1965, 32 pp. (U.S.F.S. Res. Paper Int-18).

Thomas, H.P. 1959. The absorption of radiant heat by fire fighting foam. Journal of Applied Chemistry, 9: 265-268, (1959). Reviewed in Fire Res.Abst. Sept. 1959, Vol. 1, No. 4, p. 192.

3. Laboratory Experiments Relating to Tests of Fire Fighting Chemicals

Aidun, A.R. 1961. Additives to improve the fire fighting characteristics of water. Syracuse University Research Institute, Quart. Prog. Rep't. 14-16, 98 pp., illus.

Viscous-water solutions, between 100 and 400 centipoise, were about 4 times more effective than plain water in extinguishing certain laboratory fires.

Advantages of viscous-water:

1. Since very small amounts of powder produce the desired solution viscosity, there are no severe logistic problems.
2. Not toxic.

Disadvantages of viscous-water:

1. Solution viscosity sensitive to salts in water, other chemicals, temperature, and storage conditions.
2. Solution viscosity must be maintained between 100 and 400 centipoise. Below 100, the solution will not adhere; above 400, problems develop with centrifugal pumps.
3. Both powders and solutions usually require preservatives. (Added by manufacturers of commercial brands.)

Beall, H.W., D.J. Lower and D.G. Fraser. 1948. Chemicals for forest fire fighting. Canada, Department of Mines and Resources, Dominion Forest Service, F-F Res. Leaflet No. 5, 5 pp.

Davis, J.B., et al. Gelgard - A new fire retardant for air and ground attack. Fire Technology (Boston, Mass.), 1965. p. 216-224.

Properties and characteristics of the compound are described. Gelgard is compared to other viscous agents and water on the basis of both lab and field tests.

Fraser, D.G. 1948. Penetration tests with water and wetting agents in dry moss to determine relative penetration, Petawawa Forest Experiment Station. Forest Fire Research Institute, Cat. No. 321.01.

A procedure is established for determining the amount of retention of wet-water, compared to plain water, in moss -- a fuel type that exhibits a "repellent effect" when dried.

Hardy, C.E., et al. Evaluation of forest fire retardants -- a test of chemicals on laboratory fires. Intermt. For. Res. Paper 64, 1962.

Seven commercially available long-term fire retardants are evaluated by their effectiveness on lab test fires 3 hours after application. A different ranking was obtained for no wind, and for 3 m.p.h. wind during the fire. Algin-DAP, Firetrol, and Firebrake ranked high in both 0 m.p.h. wind and 3 m.p.h. wind during the fire.

Johansen, R.W. and J.W. Shimmel. 1963. Increasing the viscosity of water and chemical fire retardants with clays and gums. Georgia Forest Research Council. Res. Pap. 19.

Thomas, P.H. Fire spread in wooden cribs. Part III. The effect of wind. Department of Scientific and Industrial Research and Fire Office's Committee Joint Research Organization. Fire Research Note 600/1965, and Note 537/1964.

Tyner, Howard D. 1941. Fire-extinguishing effectiveness of chemicals in water solution. Industrial and Engineering Chemistry: 33. January 1941, p. 60-65.

Superiority of chemical solutions over water was measured on standard lab test fires. Two measures of superiority are given for each of the 38 chemical solutions tested:

a) $$\text{Superiority} = \frac{\text{Volume water to knock down flames}}{\text{Volume solution to knock down flames}}$$

b) $$\text{Superiority} = \frac{\text{Volume water to extinguish the fire}}{\text{Volume of solution to extinguish the fire}}$$

For many of the chemicals tested, and those listed below, 2 percent solutions possessed a major portion of the extinction advantage possessed by much higher concentrations.

Superiority in Extinguishing Fire, 2% solution	Chemical in solution
1.70	Diammonium phosphate (DAP)
1.70	Phosphoric acid
1.65	Monammonium phosphate (MAP)
1.60	Boric acid

Selected conclusions from author's paper:

1. As wind speeds increased from 0 to 15, the superiority of MAP increased rapidly from 1.1 to 4.0.

2. "As extinguisher-solution application rates approach the minimum rate at which extinction can be accomplished the amount of water required increased greatly, whereas the amount of 10 percent MAP solution required remains approximately constant."

3. ". . . For effective agents studies, possession of one or both of the following capabilities seems to be important:

a) reduction of the volume of combustible gas formed (by increasing the proportion of charcoal formed).

b) formation of a fused inactive surface-protective-layer on the combustible surface."

Other factors appeared to have limited importance.

Tyner, H.D. 1967. Development of foams for use in forest fire control. Forest Fire Research Institute, Ottawa, Ont. Info. Rpt. FF-X-3.

Report on research at Petawawa, directed toward:

1. Working fire-retarding chemical compounds into the foaming agent, yet maintaining desired properties of the foam.

2. Developing laboratory test methods for selecting superior foaming agents, and the evaluation of existing agents with them.

3. Theoretical studies in surface chemistry that mai aid in search for new foaming agent formulae.

Wooliscroft, M. and M. Law. 1965. A report on forest fire field work. Fire Research Note No. 647, 1967.

Wright, J.G. Experiments on the use of chemicals in forest fire suppression. Dominion Forest Service. File Rpt. C-3, Fir Res.File 116.3203.

In the summer of 1936 tests of chemical additives were undertaken to increase the suppression effectiveness of water. Fires burning in a match-splint fuel were suppressed with water and chemical solution sprays. Efficiency of a chemical solution was calculated with the formula:

$$E = \frac{\text{Volume of solution to extinguish}}{\text{Volume of water to extinguish}} (100)$$

Ammonium sulphate solution resulted in 47% saving in water volume.

4. Combined Lab and Field Tests of Retardant Effectiveness

Davis, J.B., D.L. Dibble, et al. Gelgard - a new fire retardant for air and ground attack. Fire Technology (Boston, Mass.). 1965. 1 (216-24). Also in Fire Res. Abst. Rev., Wash. 1966. 8 (2), (110-1).

Fire Stop. 1955. Fire retardants. Progress Report No. 4.

Fons, W.L. 1950. Wet water for forest fire suppression. U.S. Forest Service, Calif. For. and Range Expt. Sta. Res. Note 71.

Results of a comparison of 14 brands of wetting agent to plain water on 93 model fires, 66 field test fires, 108 mop-up fires:

1. Savings up to 23% in the volume of water required, and 13% in time, for mopping-up fires.

2. Rekindling reduced by as much as 30% on fire mopped up with wet water compared to plain.

3. Wet water is superior in knocking down flames.

4. Dead fuels remain wet up to 50% longer on back fire lines.

The mechanisms of wet water and plain water effectiveness are reviewed. Costs of additives in 100 gallons of solution are as low as 20 cents.

Phillips, C.P. and H.R. Miller. Swelling Bentonite Clay - a new forest fire retardant. Technical Paper No. 37, Pacific Southwest Forest and Range Expt. Sta., Berkeley, Calif.

5. Field and Operational Tests

Bangtorf, C.E. 1967. Development of slip-on forest fire tankers. Fire Control Notes, Vol. 28 (2), pp. 3, 4, 16.

Slip-on tankers for jeeps and 4-wheel drives complement California's larger and permanent ground-tanker fleet. In 1964 there were 1,455 slip-ons, of which 1,277 were between 50 and 200 gallon capacity. The 50, 75, 125 and 200 gallon sizes appear to be most popular.

Brown, E. 1962. Comparative tests, chemical fire fighting agents. Rickreall Test Series No. 9. Oregon Dept. of Forestry Activities in Fire Control 2. 14 pp., illus.

Attempts to evaluate comparative effectiveness of water, viscous-water, and gel directly with operational equipment and on going fires were unsuccessful. Standard test fires were devised so that the effectiveness of three suppressants could be compared.

Charles, W. George and Charles E. Hardy. 1965. Fire retardant viscosity measured by modified Marsh Funnel Northern Forest Fire Laboratory. Int. For. Res. Expt. Sta., Ogden, Utah, Res. Note.

Tables for the relationship between Brookfield viscometer viscosity readings, and the corresponding measurement in Marsh Funnel seconds. Modified Marsh Funnels are operational tools and available from:

1. Baroid Division, National Lead Co., P.O. Box 1675, Houston, Texas.

2. Western Fire Equipment Company, 69 Main Street, San Francisco, California 94105.

Davis, J.B., et al. Viscous water and algin gel as fire control materials. Berkeley, P.S.W. For. & Range Expt. Sta. 1962.

In addition to field tests which were not too conclusive, a questionnaire was distributed to crews using viscous water and algin gel operationally. The results of this questionnaire are su marized as follows:

1. Crews using viscous water on hot fires were enthusiastic, but crews using viscous water on low intensity fires were not.

2. Crews complained of viscous water lack of penetration, its slipperyness, and in mixing and handling problems.

3. Viscous water superior to water in knocking down flames and in preventing rekindling.

4. Galvanized tanks corroded, forming a layer of zinc alginate in tanks.

Davis, J.B., D.L. Dibble and C.B. Phillips. 1961. Fire fighting chemicals. U.S.F.S. PSW Forest and Range Expt. Sta. Misc. Paper 57, 27 pp. illus.

Davis, J.B. and Clinton B. Phillips. 1965. Corrosion of air tankers by fire retardants. Calif. Air Attack Coord. Co ittee.

Findings useful in selecting materials for tank construction.

Dodge, M. and J.B. Davis. 1966. Fire retardant chemicals - an aid in slash disposal. Journ. of For., Feb. 1966, Vol. 64, No. 2.

Viscous diammonium phosphate, costing 6 to 7 cents per gallon, was a very effective retardant when applied at a rate of .11 to .15 gallons per 100 sq. ft. (i.e., 1.1 lbs. to 1.5 lbs. per 100 sq. ft.)

Maul, T.W. 1961. Testing equipment designed for ground application of viscous water and calcium alginate gel. Oregon Dept. of For. Activities in Fire Control 1, 22 pp. illus.

A truck tanker capable of delivering both viscous water and gels, developed in California, is tested on fires in heavy fuels in Oregon. Results are presented for each test fire.

Macleod, J.C. 1967. Detection and control of forest fires. Recent developments in techniques and research. Woodlands Review WR 118, p. 126.

Comments on the U.K. method of safequarding outside boundaries of prescribed burns with thickened water and the unique equipment that has been developed for its application.

Montsanto Phoschek 259 Fire retardant ... for effective ground control of grass, brush, and timber fires. Montsanto Technical Data Sheet No. I-274.

Evolution of Phoschek 259, its advantages over competitive viscous agents, and guidelines for its mixing, handling and application with ground equipment. Copies are available from:

Montsanto Chemical Co.,
Inorganic Chemicals Div.,
at
1. 800 Lindberg Blvd.,
St. Louis 66, Mssouri, U.S.A.
or
2. 175 Rexdale,
Toronto, Canada.

Tucker, L.A. 1961. Report on Washington Department of Natural Resources work with fire retardants and fire equipment. Western Forest Fire Research Committee Proceedings, 1961: 29-30.

6. Fire Behaviour

Van Wagner, C.E. 1967. Calculations on forest fire spread by flame radiation. Forestry Branch Departmental Publication No. 1185.

APPENDIX I

THE LAB TEST-FIRE PROCEDURE AND DATA

For the design of a laboratory test procedure, the author is doubly indebted to Mr. C.E. Van Wagner of the Petawawa Forest Experiment Station - for the use of his burning chamber, for his research on relating lab test-fires in Red pine litter to field fires in that fuel type. The critical contribution of this previous research to tests of retardant effectiveness is as follows:

1. For fires in windless conditions, or backing into the wind, radiative heat transfer through the fuel bed is the dominant mechanism.

2. Rate of advance in needle test beds is relatively insensitive to wind velocity, and observations on field back fires confirms this principle.

3. A needle litter test bed has been designed which is similar to the bulk density and fuel arrangement in natural stands.

Field test-fires in slash were sensitive to changes in wind direction and velocity, so, unlike the lab test-fires, there was considerable preheating of fuels by flame radiation as well as by radiation through the fuel bed.

Effectiveness comparisons on lab test fires were limited to viscous water-diammonium phosphate (abbreviated as VW-DAP) solution and plain water. Effectiveness was measured by two indices:

a. If the treatment reduced rate of advance

$$E = \frac{ROS.CONTROL - ROS.TREAT}{ROS.CONTROL}$$

where ROS.CONTROL is the rate of advance in the untreated end of the test fire, ROS.TREAT is the rate of advance in the treated portion.

b. If the treatment put the fire out,

E = minutes till it would reignite with a match = duration.

The procedure in each case was to apply a specific weight of treatment with a paint spray gun to one half of the test bed; ignite the untreated end of the test bed and time rate of advance, measure rate of advance or duration in treated portion of the test bed.

Table 4.

LAB TEST-FIRE DATA

No.	Viscous-water Series Centipoise	gms/	Mix	*1 Ros.Control f.p.m.	*2 Ros.Treated f.p.m.	*3 Effectiveness		Lb.Treatment per 100 sq.ft.
1	-	50	15% DAP	.69	.42	39.1		2.20
2	400	50	15% DAP	.46	.31	32.8		2.20
3	400	75	15% DAP	.48	0.00	100.0	20 minutes	3.31
4	400	30	15% DAP	.50	.39	22.0		1.32
5	400	100	15% DAP	.48	0.00	100.0	15 minutes	4.41
	Plain Water Series							
6	-	90	-	.58	.51	12.1		3.96
7	-	30	-	.72	.58	19.4		1.32
8	-	100	-	.77	.31	59.7		4.41
9	-	110	-	.54	0.00	100.0	10 minutes	4.85
10	-	40	-	.51	.39	23.5		1.76

*1 Rate of spread in the control portion of the test-fire.
*2 Rate of spread in the treated portion of the test-fire.
*3 Effectiveness is measured as percent reduction in rate of spread as a result of the treatment, or $E = \frac{(\text{Ros.Cont.} - \text{Ros.Treat.}}{\text{Ros.Cont.}} \times 100)$

APPENDIX II

SLASH FUEL TEST-FIRE PROCEDURE

The most important considerations in defining a test fuel are as follows:

1. The total available fuel per ground area.
2. The mass of fine fuels.
3. The density of the fuel per unit of ground area.
4. The total surface area of the fuel per unit of ground area.

Each of these factors were considered in the design of the test fire.

1. The Total Available Fuel Per Ground Area

The test fuel was loaded at a rate of .7 lbs. per sq. ft., which corresponds to 15 tons of available fuel per acre. Admittedly, slash fuels often have several pounds of fuel on some square feet, barely none on others, but 15 tons available fuel is a limit seldom exceeded even on even the most intense slash burns.

To ensure that the fuel of each test fire was of a similar moisture content, the balsam fir branches were trimmed in June and stored on racks in a fuel shelter for three months.

Moisture content samples taken in August indicated that both fine and heavy fuels had approached the moisture content of 12%.

2. The Mass of Fine Fuels

Balsam fir branches were chosen as the test fuel, because of this species' excellent needle retention in both the green and dry state. The needle complement of the test fuel is an important consideration, because its large surface-to-area ratio reduces the amount of radiation energy that must be absorbed for ignition. This quantity of energy is usually termed "the critical ignition impulse".

3. The Density of the Fuels Per Unit of Ground Area

A "fuel box" procedure was applied to ensure consistency of fuel density for each test fire. Each boxload of fuel was tested by two criteria before accepting it as a valid fuel:

1. The box must be full.
2. The fuel load must weigh 7 lbs.

When the two criteria were satisfied, the fuel was emptied onto a 2' x 5' strip. A second sample was attached to the end of the first strip to complete a 2' x 10' test bed.

4. The Total Surface Area of the Fuel per Unit of Ground Area

The fuel surface area was not known for each test fire. Variation of surface area between test fires was minimized by constructing them of only balsam fir branches with a 100% needle complement.

The final precaution, perhaps the most critical, and yet the most open to chance, was to set the test fires in similar weather conditions. Fires were set only when wind speeds were less than 5 m.p.h.

Evaluation of Test Fire Consistency

Rate of fire spread in the control portion of each test fire was analyzed statistically.

Mean rate of spread: 2.72 feet per minute.
Standard deviation: .67 feet per minute.

In other words, there is a 68% chance of a rate of spread within the limits of 2.72 plus or minus .67 f.p.m., and a 95% chance that an individual rate of spread will be within the limits 2.72 plus or minus 1.34 f.p.m.

To further reduce the effect of test fire inconsistencies, the effect of a treatment is expressed as a percentage reduction of the rate of spread in the control portion of that same test fire.

APPENDIX III

PERFORMANCE TESTS OF THE BLISS-ROCKWOOD MODEL-2 AND THE JET-X NOZZLE

A standardized performance test was applied to the two generators to determine which one produced the type of foam that, on the basis of field test fires, was the most effective. Furthermore, it was essential to know at what rate this foam could be produced.

In each performance test the following measures were taken, (see Table 5):

1. The ratio of agent to water, so that the amount and cost of additives could be calculated.
2. Foam expansion, a measure closely related to foam effectiveness.
3. Foam production rate, a measure essential to calculations of how many 100 square feet could be treated per minute, or per tankful of water.

In each test the amount of water and foaming agent pumped into the generator was weighed, and the total cubic feet of foam produced measured. Foam production rate was calculated by dividing the total cubic feet of foam produced by the time taken to produce it; and foam expansion calculated from 1-gallon foam samples. A Gorman-Rupp back-pack pump was used in each trial.

Despite attempts to standardize the performance tests, the most obvious conclusion from Table 5 is that the range of results was enormous. Part of the explanation for this variability is the variation of the delivery rate for the pump. This variation can be expected in operational conditions, however, unless sophisticated pressure gauges are used to ensure that the solution is pumped at a constant pressure. Foam samples taken immediately after production indicated a much lower solution content than calculations based on the weights of agent and water actually used. The two possible sources of error are: (1) High rate of drainage before foam sample could be taken. (2) Water wastage from filling the hose, leaks, and possibly from the generators.

Table 5.

FOAM GENERATOR PEROFRMANCE

	Agent	1. Setting	2. Solution	3. Expansion	4. C.F/M Foam Prod.	5. Solution Del.Gal.	6. C.F.Foam	7. Running Time
Bliss-Rockwood Model 2	Jet-X	3	4.74	568	975	1.7	16,160	18
	Jet-X	3	4.33	108	309	2.9	3,311	11
	Jet-X	3	6.82	252	842	3.3	7.561	9
Jet-X Nozzle	Walter-Kidde	1	1.40	102	366	3.6	3,060	8
	Jet-X	3	3.35	160	250	1.6	4,808	19

Footnotes -

1. Setting: Foaming agent inductor setting.

2. Solution: $\left(\frac{\text{lb. agent}}{\text{lb. water}} (100)\right)$ as determined by weighings.

3. Expansion: $\left(\frac{\text{ml. foam}}{\text{ml. solution}}\right)$ as measured by foam sample.

4. Cubic Feet Foam Production per Minute = $\left(\frac{\text{Cu. ft. Foam}}{\text{Production Time}}\right)$

5. Solution Delivery Rate in Gallons per Minute: This rate is the amount of solution delivered per minute that becomes foam. For incompletely under stood reasons there were large losses of solution in some trials, very little in others. This rate is therefore the maximum attainable since it is assumed that all solution is expanded into foam.

6. Cubic Feet of Foam from 300 Gallons: Total cubic feet possible with zero water wastage. Hose lays of 50 feet often require 20 gallons or more to fill the hose and foam generator to operating pressures.

7. Running Time: Minutes that generator would produce at zero water wastage, 300-gallon water load.