EFFECTIVENESS OF FOAM AS A FIRE SUPPRESSANT

Edward Stechishen and William G. Murray
Petawawa National Forestry Institute
Forestry Canada
Chalk River, Ontario

ABSTRACT

This paper gives an overview of the history of forest fire fighting foam, foam characteristics, criteria critical to product selection, the benefits of using foam, and the results of effectiveness trials and evaluations.

INTRODUCTION

The addition of substances to water to enhance the water's fire suppression characteristics was first studied extensively in the 1930s. Although numerous additives were identified as beneficial, the logistics of using these products in concert with the available equipment proved impractical. During the ensuing years, technological changes in forest fire suppression facilitated the development and use of retardants and suppressants. The additives were basically of three types: those that made water more viscous; those that chemically improved the water; and those that produced foam. Agents that made water more viscous have come and gone. Chemically altered water, i.e., as a long-term retardant, is currently widely used. Water in the bubble state (i.e., foam) is currently gaining wider acceptance.

Foam is an aqueous agglomeration of bubbles that are separated from each other by a liquid film. The main constituent in this liquid film is water. The bubble cavities are filled with air. A 1% foam having an expansion of five times has the following volumetric proportions: air, 80%; water, 19.8%; and chemical additives, 0.2%. If the expansion is 15 times, then the proportions are as follows: air, 93.3%; water, 6.6%; and chemicals, 0.1%. The chemical make-up of the foam concentrate may contain water and, therefore, the net volume of chemicals per unit volume is indeed small.

Energy balances among constituents making up this bubble structure determine the stability of the foam. Structural rearrangements from spheres to polyhedrons take place until some semblance of an energy balance is reached. The binding forces are due to the presence of surface-active agents (surfactants), which facilitate the formation of foam and permit the foam to retain its bubble structure. The diversity of the solubility of components making up the surfactant is responsible for the decrease in surface tension of water and for its foamability.

HISTORICAL OVERVIEW

The research community has been studying foam for decades to determine which additives improve the fire-fighting characteristics of water. Forestry Canada pretty well stayed on the sidelines until the 1960s, at which time research was undertaken internally by employees and also by contractors. Their main objective was to produce a satisfactory foam in the presence of 2% mono- or di-ammonium phosphate and to test its use in the field. This meant searching out existing agents that would fulfill this need. Research by Forestry Canada was terminated around 1970 for lack of any major breakthrough. The foams that could be generated using existing products had too high an expansion rate and lacked the stability required for forest fire use. In the ensuing years attention was focused on convincing people in industry that there was a potential for marketing a slow-draining low-expansion foam agent to the forestry sector. These overtures met with little success for nearly a decade until Lorcon Incorporated of Ottawa expressed an interest. This interest led to the development of SILV-EX, which was first used operationally in 1985.

Preliminary Evaluations

First aerial tests with formulations prior to developing SILV-EX were conducted in New Brunswick in 1982. Air tanker drops made on grass, slash, and standing timber were used to identify product weaknesses. It turned out that the mix ratio and foam expansion were too high and the drainage rate of the foam was much too fast. The formulation that emerged in the marketplace (SILV-EX) in 1985 was used operationally on wildfire in British Columbia and experimentally in France, Corsica, and Spain. The overseas tests permitted us to evaluate the CL-215 as a foam generator, to determine the coverage of and canopy penetration by the foam, to identify aerial delivery limitations, and to determine the foam's worth as a suppressant. The following conclusions were made:

1. The foam does an excellent job of enveloping the fuels compared to water.
2. The foam not only coats the fuels but it also adheres well.
3. The CL-215 is a good foam generator and it delivers a stable foam that remains on the fuel for an extended period of time.
4. The foam isolates the fuel particles from oxygen and impedes combustion.
5. The foam acts as a much better heat sink than water and reduces the impact of impinging radiant energy.
6. The bubble structure impedes the rate of water evaporation.
7. The foam acts as a surfactant as it reverts to the fluid state, and runoff is reduced because the release of water is gradual. Hence it has a better opportunity to wet the fuels.
8. The white foam is very visible and it acts as a drop marker for air crews.
9. The foam acts as a marker for mop-up crews, i.e., hot spots exist only where total breakdown of the foam is detected.
10. The foam-treated fuels do not seem to rekindle as readily as those treated with plain water.

The question "how much better than water" was never answered, however. Several foam drops were made at the airport in Pembroke, Ontario, to get specific drop pattern data later the same year. The idea of using foam for forest fire suppression had come of age, and its acceptance as a suppressant is now history.

FOAM CHARACTERISTICS

Water is noted for its extraordinary cooling properties, but its use in extinguishing fires is limited by its low viscosity, limited blanketing capabilities, and poor reflectance characteristics. The conversion of liquid water into a stable bubble structure is an attempt to overcome these shortcomings. The amount of water that adheres to a fuel particle depends on its surface roughness. During aerial application the contact time of falling water with the fuel's surface is short; consequently, all excess liquid drains off. Foam, on the other hand, is influenced by surface roughness at the moment of contact, but the surplus may not drain off. The total that adheres is dependent on the foam's structure and bubble stability. The amount of water trapped in the bubble structure may be several times greater on a per-unit-area basis than if liquid water was applied. This is particularly true if bridging occurs between particles. The change in flow characteristics overcomes liquid water's low viscosity, and the change in structure improves water's blanketing capabilities (Fig. 1). This schematic assumes equal amounts of water per unit surface area and a foam expansion of 10 times. The foam provides good blanketing, and its brilliant whiteness acts as a reflective surface.

Dispersion and Mixability

One of the least known or the least publicized facts about foam concentrates is that they do not disperse instantaneously when added to water without agitation. Although their specific gravities range from 1.015 to 1.038, the material has a tendency to settle to the bottom of the tank. The result is that most of the active ingredients end up in the bottom third of the container of water. This occurs irrespective of the temperature of the water or its salinity level. The drainage curves in Figure 2 confirm excessive settling in warm water and also in cold water (Fig. 3). Saline water may entrap the concentrate at the water's surface and cause it to settle to the bottom slowly. Sampling prior to completion of transferring concentrates will reveal an enriched upper layer (Fig. 4) and an enriched lower layer within a container of water. The "well stirred" curve represents the foam developed using a homogeneous solution.

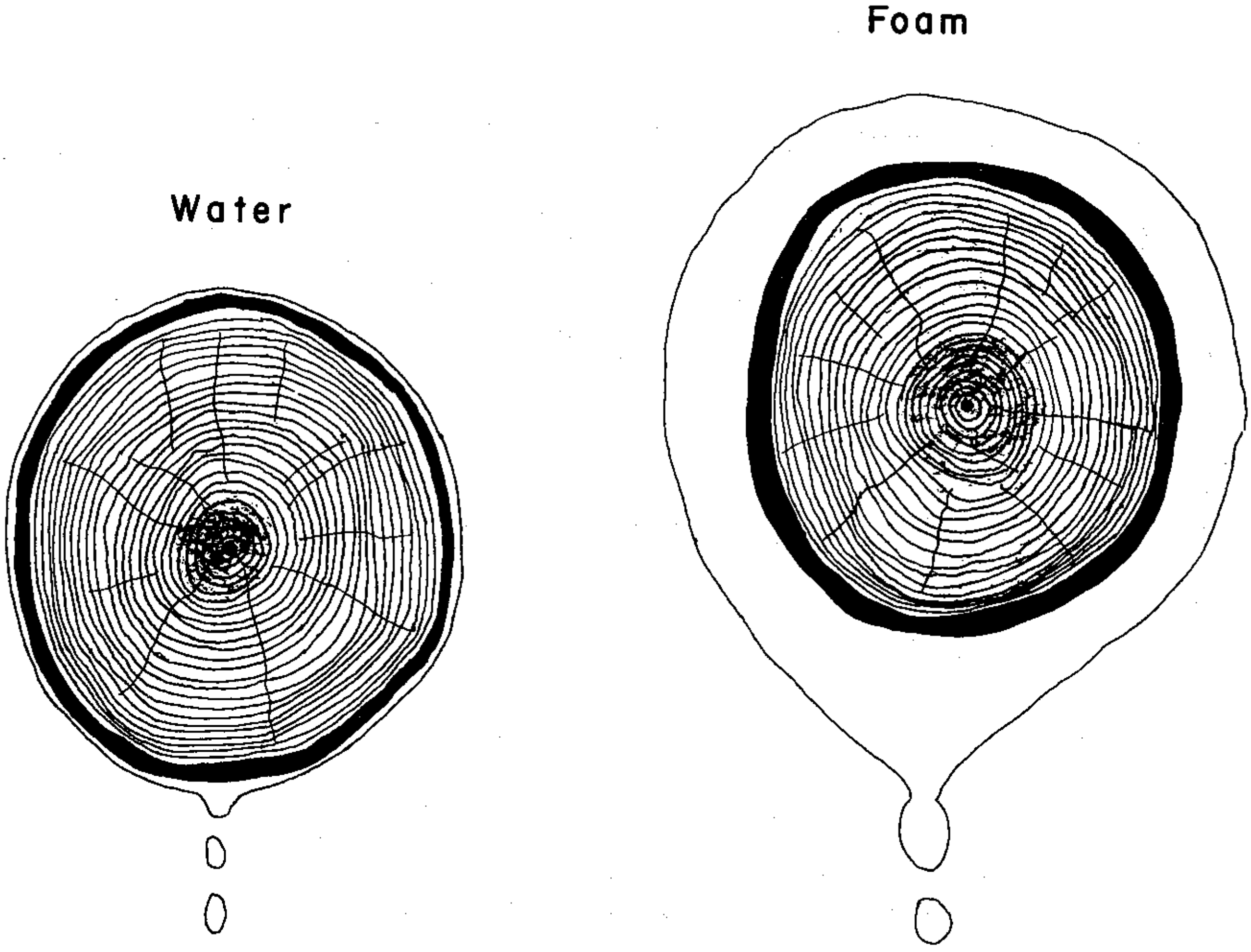

Figure 1. Coatings represent equal amounts of available water on each fuel surface (cross-section view) using an expansion of 10 times for the foam.

Health and Safety

The fact that the skull and crossbones are not prominently displayed on the label does not mean that handling precautions should not be exercised. The chemicals that make up the foam-generating agents smart the eyes much the same as shampoo. Ingestion of these products will result in diarrhea, which may require medical attention depending on the quantity consumed. Prolonged exposure may affect those with very sensitive skin. By practicing good hygiene, ensuring that the water used for human consumption has not been contaminated, and by changing soiled garments frequently, no adverse reaction should be encountered. Because foam products are degreasers, hand creams may be required to replenish the loss of skin oils.

Environmental Considerations

Policies concerning environmental issues are developed and enforced by provincial agencies. Consequently, the stance taken by each agency concerning

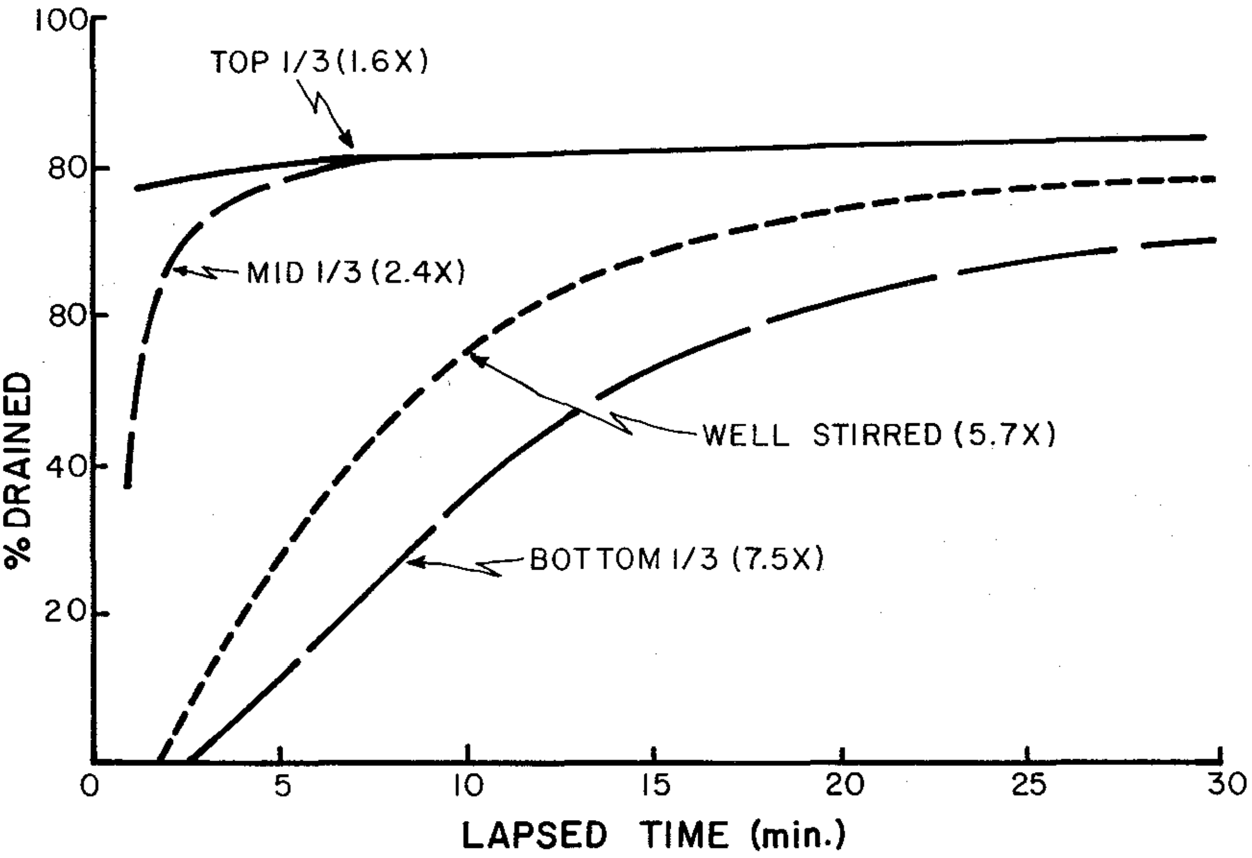

Figure 2. Effect of non-agitation on dispersal of foam concentrate added to distilled water having a temperature of 23.5°C in comparison with a well-stirred 0.65% solution.

acceptable levels of discharge and contamination is different. The question is: "Should the populace be concerned about wholesale use of foam in the natural environment when the use of herbicides and pesticides is tolerated"? The rate of biodegradability of foam constituents is likely much more rapid, and the end products are for the most part naturally occurring products. Above all, the level of application and the percentage of concentrate used in these solutions is low. Industry will respond and reformulate if its products prove unacceptable to any agency. Foliar damage to vegetation from topical applications, based on trials conducted at the Petawawa National Forestry Institute (PNFI), proved insignificant if the vegetation got rained on occasionally. Conifer seedling mortality occurred, however, when the plant roots were continually fed with a foam solution. Contamination of water bodies should be avoided at all cost because the surfactants interfere with the ability of aquatic life to extract oxygen.

Expansion

Expansion has little relevance to the characteristics of the foam that is produced as long as it remains low. Each foam generator has its own limitations. A given percentage of foam concentrate will therefore yield a foam having a different expansion. The curves in Figure 5 are indicative of the diversity of expansions for different generators using a 1% solution. The Dromader M-18 flying at 166 km/h produced foam

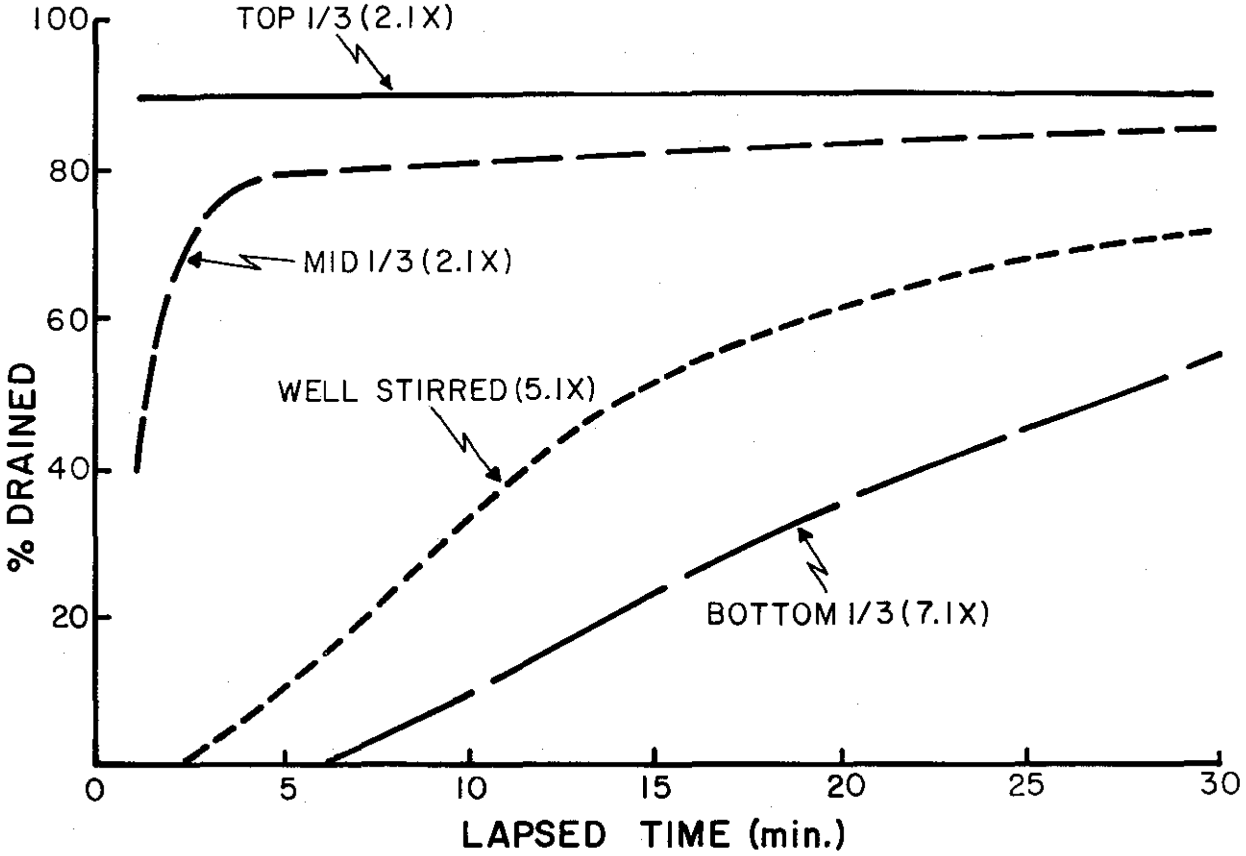

Figure 3. Effect of non-agitation on dispersal of foam concentrate added to distilled water having a temperature of 12°C in comparison with a well-stirred 1% solution.

having the same drainage as the PNFI laboratory compressed air system, yet the M-18-generated foam expansion was more than three times as high. The CL-215-generated foam and the blender-generated foam had the same drainage characteristics, but expansion was 11.3 for the former and only 5.4 for the latter. Foam produced by the M-18 drained faster than the CL-215 generated foam. The foam generated by the WAJAX Mark III pump system using a CO-SON MF-16 foam nozzle drained even faster than the air tanker foams, and its expansion was 17 times. These results indicate the lack of correlation between expansion and drainage characteristics. The stability of the bubble structure cannot be assessed using expansion information.

Drainage and Foam Life

The important factor in assessing foam quality is drainage. The rate of drainage gives a time-related reference to the location of the fluid that is released from the bubble structure. Fuels are wetted by this free liquid. A regulated release rate is therefore most desirable. In defining the optimum liquid release rate it is necessary to consider where the foam comes to rest and what happens to it with time. In a multistoried fuel structure, drainage must be accelerated if adequate wetting is required near the ground to stop the spread of a surface fire below the canopy. In such situations a lower mix ratio is required to promote more-rapid drainage.

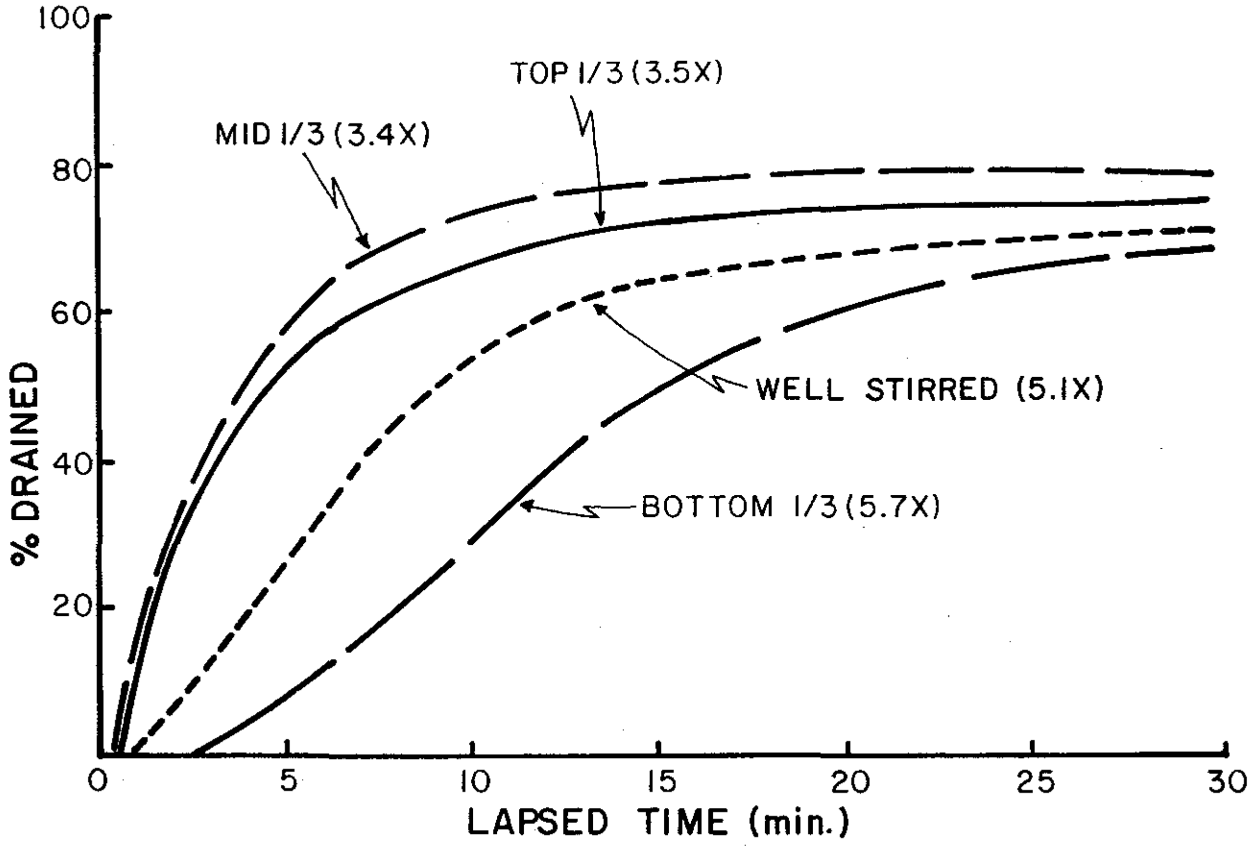

Figure 4. Effect of non-agitation on dispersal of foam concentrate added to salt water having a temperature of 12°C in comparison with a well-stirred 1% solution.

Drainage characteristics essentially tell you whether the foam remains relatively stable for some duration upon landing. The stability of the foam will determine how fast or slow the water filters down to wet the fuel at the lower levels. The drainage characteristics assist the user in determining the mix ratio required for a given generating system to meet a specific need. The curves in Figure 6 reflect the rate of drainage for foam produced by the WAJAX Mark III pumping system using a WAJAX nozzle. Not only do the curves identify that this nozzle cannot effectively utilize the extra concentrate fed into the system beyond the E setting, they also identify how much fluid still remains locked in the bubble structure at any given time following application.

Product Selection

The foam concentrates are not markedly different from each other in terms of the quality of the foam they produce, but some differences may be significant for any particular user's situation. One very important characteristic that must be considered is the viscosity of the concentrate. If these products are used at temperatures above 30°C there is little need for concern, but as the operating temperature decreases, changes in viscosity cannot be ignored. The temperature-viscosity relationships (Fig. 7) vary according to product brand. This increase in viscosity means that as the resistance to flow increases, the pumping, metering, and induction rates will decrease. Product

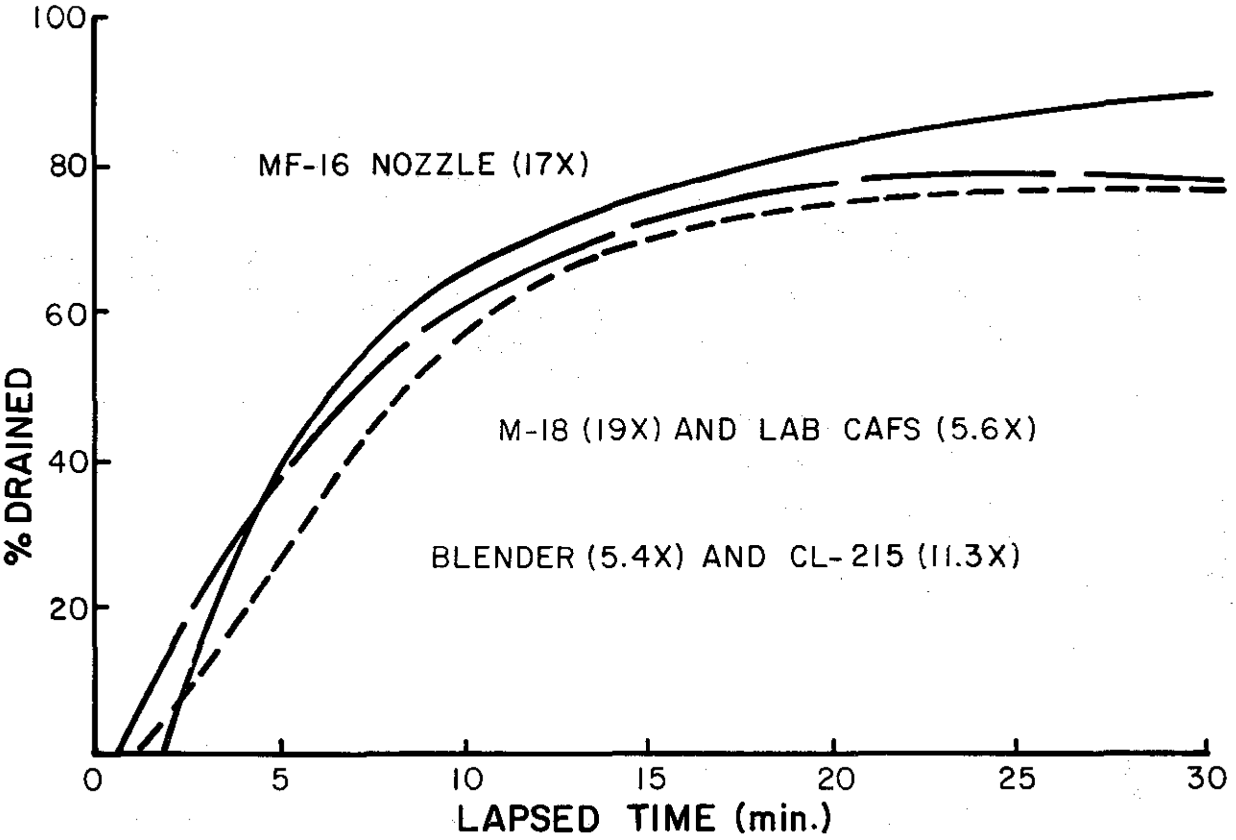

Figure 5. Drainage and expansion comparisons for 1% foams generated by different systems.

brands 'A' and 'B' are least affected by cooling from 30°C to 3°C. Although their viscosity values doubled, the pumping rate decreased by only 15%. Brand 'C', on the other hand, thickens significantly: a fourfold increase in viscosity resulted in a 60% decrease in pumping rate. Brand 'D' was most susceptible to chilling, and its flow characteristics changed drastically at temperatures below 15°C. The important thing to remember is that pumping or injection times must be adjusted as concentrate temperature declines if foam quality is to be maintained.

The next logical concern is how water temperature affects the foam's drainage rate. The standard drainage curve in Figure 8 was arbitrarily selected as representative of a slow-draining foam suitable for forest fire suppression (i.e., a foam that would adequately wet the fuel it contacts and would also drip off and wet fuels at lower levels). The mix percentages were varied for each brand until the curves in Figure 9 were defined to represent the percentage of each product required to maintain the specified drainage-time relationship over the water temperature range of 3-24°C. It is evident that water temperature has an affect on foam stability. The decrease in percent drained during the first 15 minutes for one of the brands is shown in Figure 10. Because the percentage required decreases with declining temperature, the user can elect to forego any adjustments in the mix ratio.

A more important consideration concerning water is its salinity level. All brands of foam are negatively affected by dissolved salts. The extreme case would be the use of sea water. Foams generated using saline waters drain much faster than freshwater foams (Fig. 11). There is a definite need to compensate for the diminution of foam quality when sea water is used.

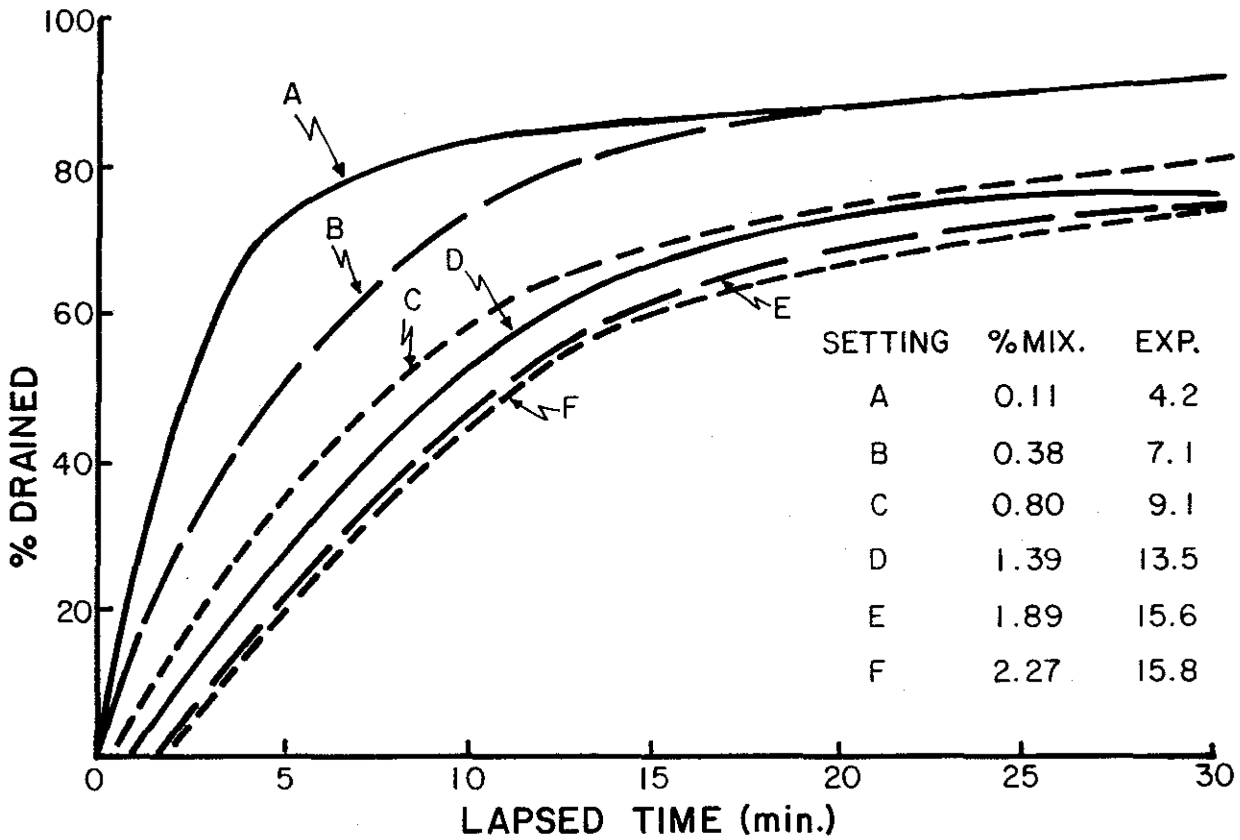

Figure 6. Drainage characteristics of foam generated by a WAJAX Mark 3 pumping system with a WAJAX foam nozzle for Fleck Bros. metering device setting A to F.

The level of dissolved chemicals must be much higher than is found in hard water before any adjustments in mix ratio are required for inland water sources.

Overwintering of foam concentrates should not pose any problem provided the liquid is recycled in spring to ensure homogeneity. Samples of four brands were freeze-thaw cycled 10 times with drainage runs executed after each cycle. There was no change in the drainage rates (Fig. 12). Storage should be in plastic containers or plastic-lined containers because contact with metal reduces the concentrate's ability to generate foam. Exposure to air induces evaporation and crystallization of some products. Ordinary venting of storage containers does not permit enough of an air-vapor interchange to affect the foam concentrate. Limited exposure to air results in an 18-36% loss depending on product brand. Unrestricted exposure to air results in the formation of a semifluid to crystalline state.

BENEFITS OF USING FOAM

Water is water whatever its form so why then use it in its foam state? The conversion of the liquid to a bubble state imparts new characteristics and enhances others to give "expanded water." This form has superior suppression qualities. These enhanced or acquired values are as follows:

1. It insulates the fuel. The pathway through a bubble mass is made up of the fluid in the bubble skins and air within these bubbles. There, the air cells

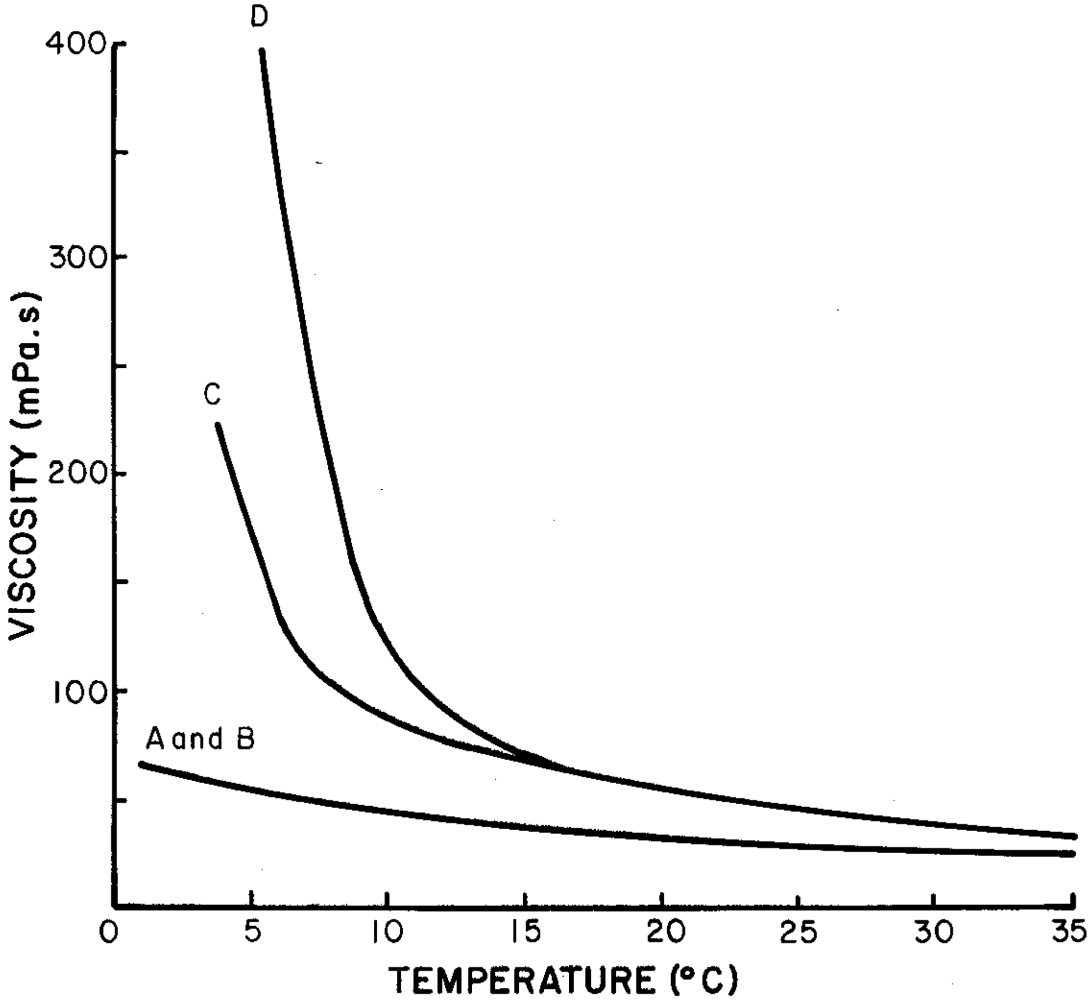

Figure 7. Foam concentrate viscosity-temperature relationship.

act as pockets of insulation. Radiant energy becomes highly diffused when it strikes the foam.

2. It acts as a heat sink. Energy impinging on the foam is diffused by the bubble structure and preheating is not localized. The energy is dissipated laterally, and the potential for rekindling or ignition is lessened.

3. It excludes air. Live coals readily vaporize off sufficient water to permit entry and mixing of oxygen-enriched air with volatiles from glowing embers. The result is rekindling of fuels and a return to flaming combustion. The foam blanket, on the other hand, acts as a durable barrier for a limited time. It dissipates energy, retards burn-through, and impedes entry of oxygen-enriched air to the combustion site.

4. It modifies the microclimate at the fuel's surface. Vaporized water at the fuel interface is trapped by the foam layer, and air pockets in the fuel's proximity attain high relative humidities. The foam impedes free air exchange and the replacement of moisture laden air with dry air.

5. It modifies the microclimate within a stand. Foam breakdown (i.e., conversion from bubble to liquid

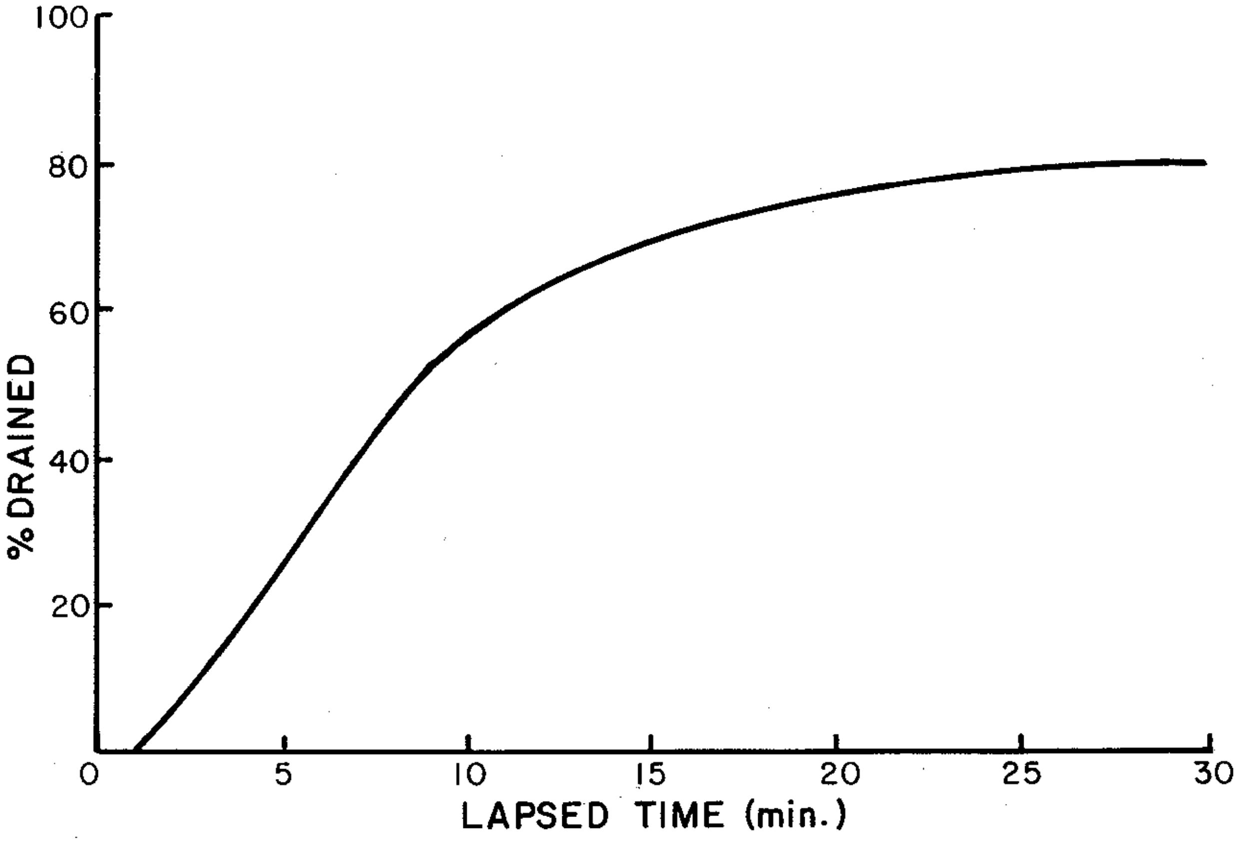

Figure 8. Drainage curve selected as a standard curve for comparing products.

state) at a controlled rate sets up a steady drip (almost a drizzle) that elevates the relative humidity of the air within the forest stand.

6. It wets the fuel more effectively. The surface-active agent in the foam reduces the surface tension of water from 72 dynes/cm to less than 33 dynes/cm. A drop of water in pure form sits on a dry surface like a marble, but, with the addition of a surfactant, this same volume of water will flatten out and spread over a much larger area on this same surface. Wetting agents enhance the water's ability to wet and to penetrate porous materials. Only a thin film of water adheres to a fuel particle depending on surface roughness, and the balance that strikes this surface drains off. Foam stops where it lands and regulates the release of fluid to wet the fuel surface and to penetrate it. The result is more-efficient wetting.

7. It drains at a controlled rate. The rate at which the bubble structure releases water and breaks down is dependent on the mix concentration and the efficiency of the foam generator. The more uniform the bubble structure, the more stable the foam. Bubble uniformity, mix percentage, and exposure to sunlight and wind determine how fast the fluid is released. By releasing the fluid slowly, liquid water is made available for a longer period of time to wet the fuel.

8. It envelops the fuel. On coming to rest on fuel particles, the excess foam does not drain off instantaneously like water but flows gradually, thereby enveloping the particles.

9. It penetrates fuel complexes. Water travels along the path imposed on it by the acting forces i.e., gravity and those imparted to it by the delivery vehicle. These same forces act on the foam, but

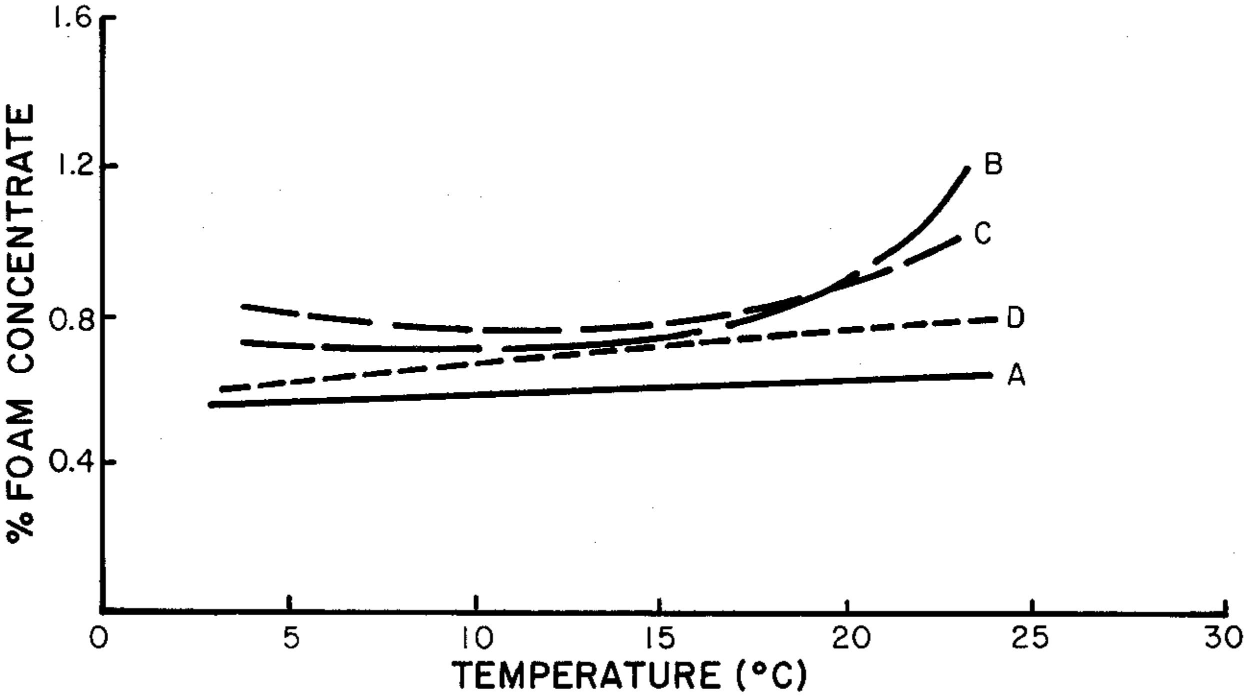

Figure 9. Mix percent required to overcome effect of water temperature and to maintain the same rate of drainage for all product brands.

because of the foam's buoyancy, imposed or induced air movement will alter the foam's descent path. Foam dropped into a canopy has a tendency to drift around and penetrate through openings to envelope fuels that might otherwise not be wetted.

10. It isolates volatile substances. The enveloping of fuels by foam results in an isolation of the volatilization of fuel from the surrounding air. The foam essentially seals in volatile substances and interferes with their combustion.

11. It dilutes volatile substances. These substances, evolving from fuel particles coated with foam, are diluted with the water vapor that builds up at the fuel interface due to absorption of heat by foam. The result is a moisture-enriched gaseous mixture that has a greatly altered ignition threshold, i.e., ignition temperature is elevated.

12. It adheres to fuels. The amount of water that lands on a fuel particle may be many times the amount that actually adheres to the fuel's surface. Foam has flow characteristics unlike those of water. Thus, much more water can be held by the bubble structure per unit area of fuel surface. An increase in amount means more available water for wetting and more available to absorb heat.

13. It increases the amount of available water. Nonwetting (waxy type) surfaces shed water, but when foam is applied, foam adheres to waxy surfaces and wets them via the wetting agent. Vertical surfaces intercept very little water even if they are receptive to water, but in the foam state a substantially greater amount of water can be entrapped.

14. It is visible. Fuels treated with water are difficult to discern from untreated; however, an application of foam is clearly visible for long distances from both the ground and the air. The white is visible against all background colors. This improved visibility aids in better tie-in of air tanker drops and increases the overall attack and mop-up efficiency.

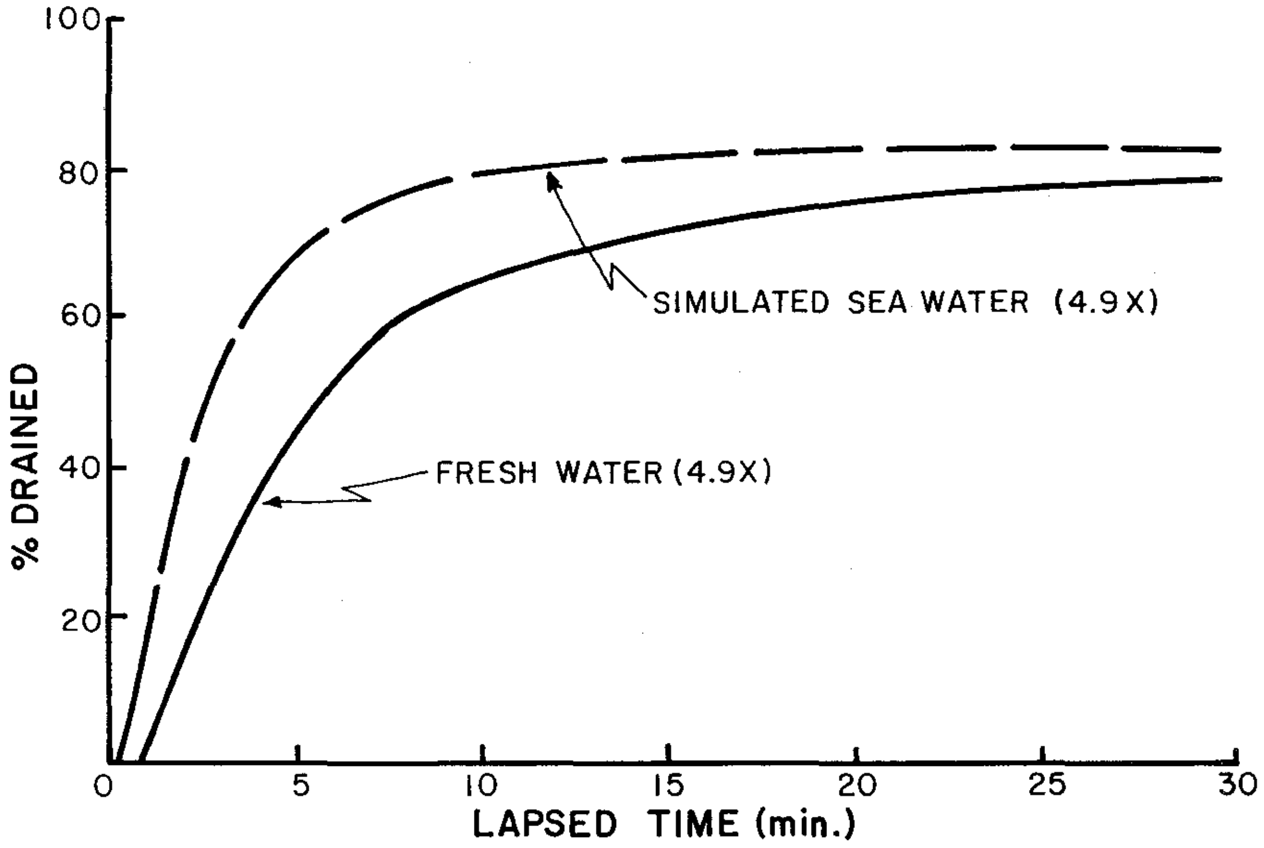

Figure 10. Foam drainage rate difference due to water temperature for 0.6% solution.

15. It inhibits rekindling. In essence, the combination of foam benefits identified in above numbers 1-4, 6-8, and 10-13 inclusive are collectively responsible for the foam's enhanced suppression qualities. The energy released at the combustion interface is dissipated, and cooling takes place.

Together with increased wetting of the combustible fuel, the inhibiting factors reduce the potential for rekindling. Rekindling only takes place where the energy output exceeds that needed to totally dissipate the foam cover. Hot spots that burn through the foam require further suppressive action, whereas all others will suffocate given time.

CONCLUDING REMARKS

The discussion thus far has dealt only with the many factors responsible for enhancing the effectiveness of water when it is bound up in bubble structure. Various claims have been made on how much more effective foam is compared to water, but this information has never been backed up with firm data. Our experience has been that data collection is hampered by over-application, i.e., the amount of foam that was applied exceeded the requirement for the intensity of the particular fire's edge. To determine the critical balance point between go/no-go of the fire's front to the application level, a series of test burns were

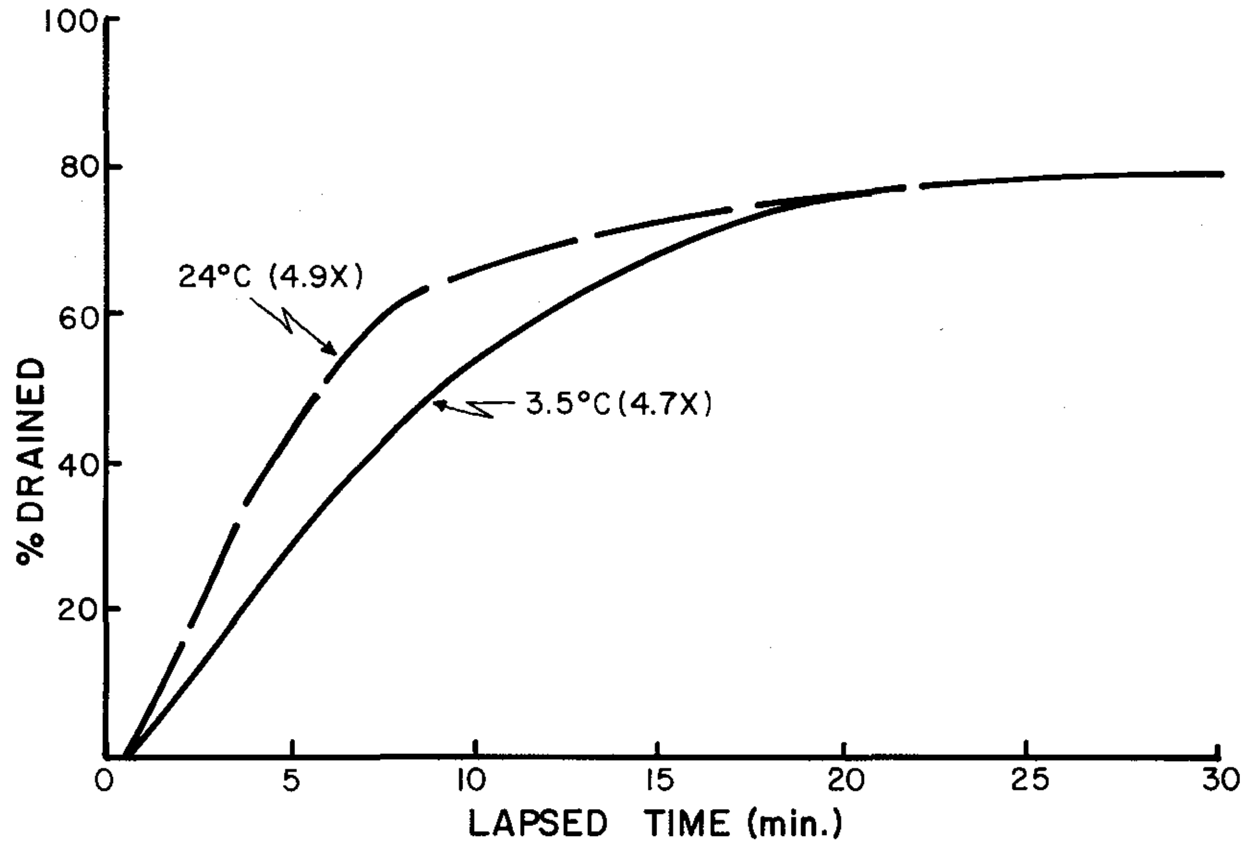

Figure 11. Foam drainage rates using fresh and simulated sea water (0.6% solution at 24°C).

conducted in the laboratory at the Petawawa National Forestry Institute. The results thus far indicate that fires in porous fuel beds (i.e., slash beds with visible openings throughout the full depth of the bed) required 28% less water in the foam state than in the liquid state. Beds that formed a continuous mat, such as balsam fir slash beds, did not permit the foam to coat particles through the entire bed depth, and the requirement to suppress fires in these beds was the same for water and foam. The rate of fire spread was drastically reduced, but under-burning propelled the fire along. It was obvious that the benefits of using foam depended on encapsulating the fuel particles with the bubble mass.

THE AUTHORS

ED STECHISHEN is the Project Leader for Fire Suppression Systems research at the Petawawa National Forestry Institute (PNFI) of Forestry Canada located at Chalk River, Ontario. He worked as a Conservation Officer with the province of Manitoba from 1950 to 1964. Ed received a B.Sc. degree in forestry (1969) and an M.Sc. degree in forestry (1973) from the University of New Brunswick. He worked as Research Officer (1969-79) at the former Forestry Canada Forest Fire Research Institute in Ottawa, Ontario, prior to transferring to his present position at PNFI.

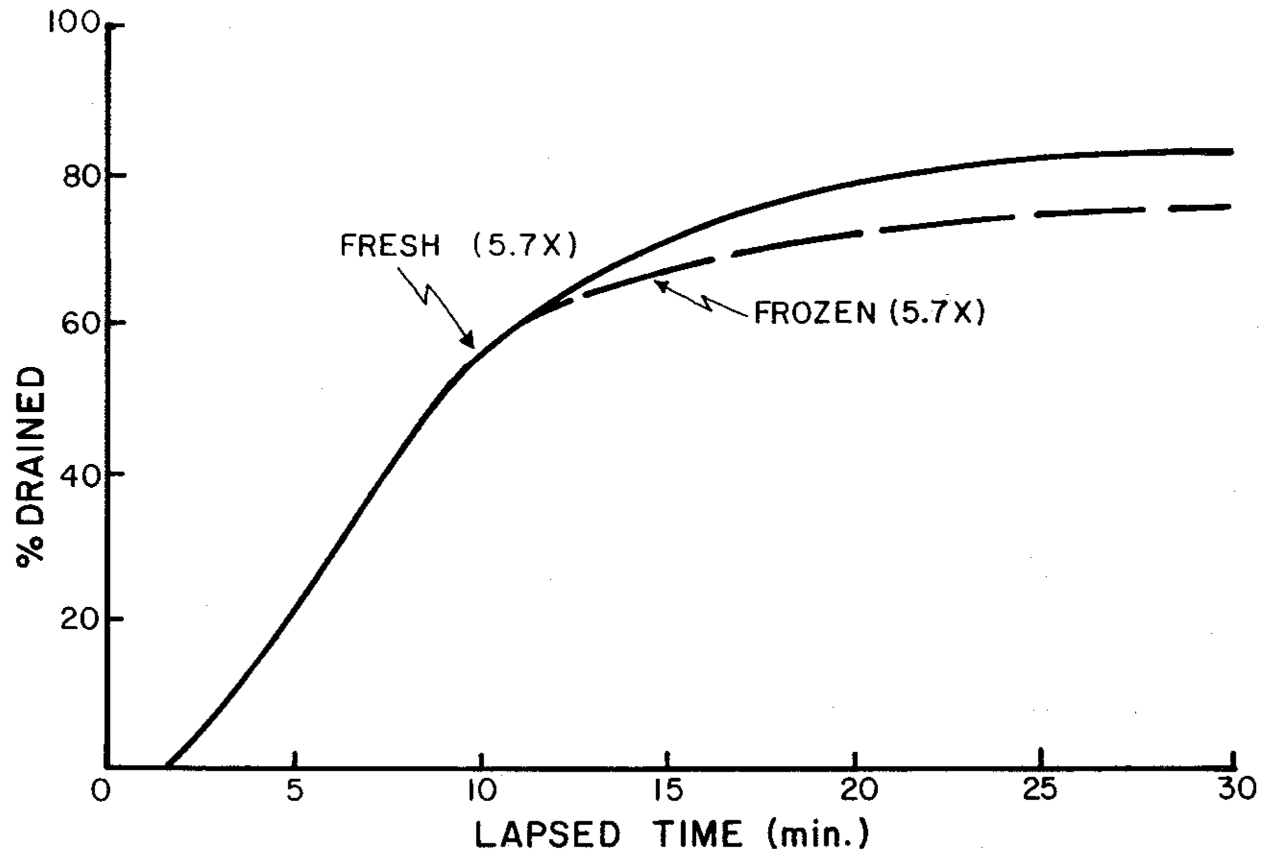

Figure 12. **Comparison of rate of foam drainage for 0.65% solutions using fresh concentrate and concentrate which was frozen.**

BILL MURRAY is a Fire Research Technician assigned to Fire Suppression Systems research at the Petawawa National Forestry Institute (PNFI) of Forestry Canada located at Chalk River, Ontario. He received a diploma from the Maritime Forest Ranger School in 1956. Bill worked for Northwestern Pulp and Power Ltd. in Alberta (1957-59) before commencing employment with the fire research group at PNFI in 1960.

THE ART AND SCIENCE OF FIRE MANAGEMENT

Proceedings of the
First Interior West Fire Council Annual Meeting and Workshop
Kananaskis Village, Alberta,
October 24-27, 1988

M.E. Alexander[1] *and G.F. Bisgrove*[2]
Technical coordinators

INFORMATION REPORT NOR-X-309

FORESTRY CANADA
NORTHWEST REGION
NORTHERN FORESTRY CENTRE
1990

This publication was printed with funds provided by the
Government of the Northwest Territories
and Alberta Forestry, Lands and Wildlife.

---

[1] Fire Research Officer, Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta.

[2] Manager, Wildfire and Aviation Operations, Alberta Forest Service, Forest Protection Branch, Edmonton, Alberta. Present address: Forest Superintendent, Alberta Forest Service, Whitecourt Forest, Whitecourt, Alberta.

Catalogue No. Fo46-12/309E
ISBN 0-662-17315-5
ISSN 0704-7673

This publication is available at no charge from:
Forestry Canada
Northwest Region
Northern Forestry Centre
5320 - 122 Street
Edmonton, Alberta
T6H 3S5

A microfiche edition of this publication may be purchased from:
Micromedia Ltd.
Place du Portage
165, Hôtel-de-Ville
Hull, Quebec
J8X 3X2

Printed in Canada

Alexander, M.E.; Bisgrove, G.F. Technical coordinators. 1990. *The art and science of fire management.* Proceedings of the First Interior West Fire Council Annual Meeting and Workshop, Kananaskis Village, Alberta, October 24-27, 1988. For. Can., Northwest Reg., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-309.

ABSTRACT

A workshop dealing with the art and science of fire management was held October 24-27, 1988, at Kananaskis Village, Alberta, in association with the first annual meeting of the Interior West Fire Council. A total of 36 invited presentations were made, preceded by a keynote address and followed by a workshop summary, involving four technical sessions: fire management problems and opportunities; fire research programs in support of fire management decisions and solutions; the role of new technologies, analytical systems, and support services in fire management activities; and fire management actions and practices. The luncheon and banquet addresses, poster session abstracts, and field trip notes are also chronicled.

RÉSUMÉ

Un atelier portant sur l'art et la science de la gestion des incendies s'est tenu du 24 au 27 octobre 1988 au village de Kananaskis, en Alberta, lors de la première réunion annuelle de l'Interior West Fire Council. Le tout a débuté par un mot de bienvenue suivi de 36 exposés qui avaient été sollicités et d'un atelier comportant quatre séances techniques: problèmes et possibilités de gestion des incendies; programmes de recherche sur les incendies à l'appui des décisions et des solutions en matière de gestion des incendies; rôle des nouvelles technologies, des systèmes d'analyse et des services de soutien lors des activités de gestion des incendies; et activités et méthodes de gestion des incendies. Le rapport fait également état des discours prononcés lors du déjeûner et du banquet, résume les séances de présentation d'affiches et présente des notes sur les excursions qui se sont déroulées.