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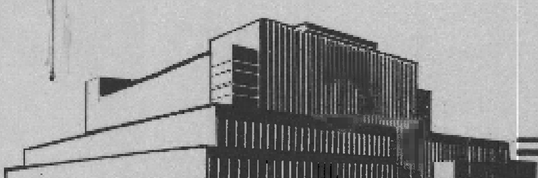

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

THE USE OF CHEMICALS IN FOREST FIRE CONTROL

By

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Research studies were undertaken in 1936 by the United States Forest Service, with the objective of learning whether chemicals could be used to advantage in forest fire control and suppression. Studies (1, 5, 8)[3] of limited extent had been made at various times in the past, but no continuous and comprehensive investigation had ever before been attempted in this country. The use of chemicals as extinguishers for other classes of fires and under other conditions has stimulated the interest of both the public and those responsible for the protection of forest areas from fire in the possibilities of their use in forest fire suppression. To the chemist, familiar with combustion and its control, the possibility of finding a material that is outstandingly superior to water or to existing chemical extinguishers has not seemed particularly promising. To the fire fighter who has an understanding of conditions surrounding forest fires, the use of chemicals as an agent in control and suppression has perhaps been more of a hope than an expected development. However, the desire to employ all available ways and means of combating forest fires and to discover, if possible, any new materials of value, led the Forest Service to undertake a study of the possibility of making effective use of chemicals.

It was recognized at the beginning that forest fires present a situation not at all analagous to the type of fires and the conditions under which chemical extinguishers are now largely employed. The principal characteristics of forest fires as related to the possible use of chemicals are: (a) They occur in the open with an abundant supply of oxygen for combustion and frequently under substantial wind velocities or air drafts. (b) The fuels are almost

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Numbers in parentheses refer to list of references at the end of this report.

entirely cellulosic, with a wide range in form, size, and arrangement. Heavy timbers, grasses, leaves and needles, limbs and branches, rotten wood and peat are but a few examples of the types of materials involved. (c) A large percentage of forest fires occur in more or less inaccessible areas where transportation is difficult, water is often scarce, and the only equipment available during the early stages of attack are hand tools, such as shovels, axes, and back packs for water.

The purpose of this paper is to present the results of the investigation begun at the Forest Products Laboratory in 1936 and continued through 1937 and 1938. The results pertain primarily to the use of chemicals in water solutions, although the results of some tests on chemical foams are included. The data are from laboratory investigations and from field tests on fuels in several forest regions of the country.

Method of Investigation

The investigation involved three steps: (a) review of the literature and search for promising materials, (b) laboratory tests to compare the effects of various compounds and to study variables in extinguishing fires in wood, and (c) field tests to compare results of the more promising materials on natural fuels of different types and arrangement.

The survey of the literature covered some 440 papers, patents, and other references, and indicated that a large number of materials in one form or another have been proposed or tried as extinguishing agents or retardants to combustion. Most of these may be classified as (a) gases, which alone or in mixtures with air of proper concentrations will not support combustion, for example, carbon dioxide; (b) liquids, which may be a single component, such as carbon tetrachloride, or water solutions of one or more chemicals; (c) solids, such as dry sodium bicarbonate; and (d) foams, most of which are a mixture of water, chemicals, and carbon dioxide gas. Some materials may occur in two or more forms, for example, carbon dioxide which is available as gas, liquid, or solid.

The usefulness of gases as extinguishing agents is generally considered to be limited to fires in flammable liquids or to other burning materials in confined spaces where the fuel can be covered or surrounded by the necessary concentration of gas to prohibit combustion. This involves maintaining a layer of gas over the fuel until it has cooled below the combustion temperature. For materials burning in the open and in deeply glowing fuels where a considerable accumulation of heat exists, this condition is generally impractical to obtain. For these reasons, gases, which are effective under special situations, do not appear to offer promise as forest fire extinguishers.

Solids have been suggested primarily because of their smothering effects. This may result from a liberation of combustion-retarding gases or from the air-excluding action of inert materials combined with their mass cooling effect. The bicarbonates, some of which liberate carbon dioxide at fire temperatures, and dusts of heat-resistant compounds illustrate the types of materials involved. The action of finely divided soil (dust) is familiar to most forest fire fighters.

The blanketing action of foams, which is of value on burning oils, is generally regarded as of less significance on fuels of the type involved in forest fires. While foam-type extinguishers are recognized as of value for fires in wood, paper, textiles, and the like, they are not necessarily considered superior to water or solutions containing large percentages of water (6, 10). However, the increase in volume of foams over the original chemical solutions, as a result of entrapped carbon dioxide, seemed to offer large theoretical advantages and stimulated considerable interest in their possible use in forest fire suppression.

Based on a consideration of the types of fuels involved, the conditions surrounding forest fires, the extinguishing action and limitations of various chemical agents, and the equipment and problems involved in use, it was decided to confine the investigation primarily to water solutions of chemicals. Water is now used extensively and it seemed possible that chemical solutions might be used in the same equipment. Some tests were included on foams in order to compare them with the more promising chemical solutions and water, although the use of foams would obviously entail special equipment.

The choice of chemicals for test in water solutions was based in large part upon the work of previous investigators but a few were included because of theoretical or other considerations. Barrett (1), Mitchell (5), Stickel (8), and others in the Forest Service had gotten some encouraging results with potassium carbonate and calcium chloride a number of years ago. Thomas and Hochwalt (9) had reported marked effects for solutions of potassium and sodium salts in extinguishing gasoline fires. Work at the Forest Products Laboratory had compared the fire retarding action of a large number of chemicals when impregnated into wood (3). Russian investigators (7), in 1932 and subsequent years, had investigated several chemicals to determine their value in forest fire control. From these various sources and others the list of chemicals for test was prepared.

Laboratory Studies

Laboratory tests were used as a method of getting within a limited time the comparative extinguishing properties of a considerable number of chemicals in water solutions of different concentrations. More than 800 standardized and controlled small-scale, fire-extinction tests were made with different chemical compounds and concentrations of solutions. The usual procedure was to make extinction tests on a standard wood fire with a 25 to 30 percent (by weight) water solution of a given chemical and, if it showed appreciably higher effectiveness than water and was otherwise promising, additional tests at lower concentrations were made.

The method of test was an adaptation of that used by Folke (2), a Danish investigator, in a study of the factors involved in fire extinction. The standard fuel pile consisted of 18 pieces, 1 by 1 by 6 inches in size, of clear, surfaced, southern pine wood. After conditioning to 6 to 7 percent moisture content, the pieces were selected by density to give a total weight of approximately 990 grams (2.18 pounds) for the eighteen pieces. The pieces were arranged in the form of a crib -- three in a layer and six layers high (fig. 1) -- on a wire screen attached to the platform of a scale that permitted continuous reading of the weight during test. The wood was ignited by means of a battery of four gas flames placed directly beneath the crib for 1 minute. The burning was allowed to progress until 50 percent of the original weight of the crib was lost at which time extinguishing began (fig. 1B). The liquid was applied as a small jet from a glass nozzle at a predetermined and controlled rate.

Data were recorded of the volume of liquid used for flame extinction and for total extinction (including glow), of elapsed time for flame and for total extinction, and of the crib residue remaining after complete extinction. A series of several tests was made with each chemical solution and concentration. Similar tests were made using water as the extinguishing agent, to afford a basis for evaluating the effectiveness of the chemical solutions.

The comparison of the various chemical solutions and water was made at a constant rate of application of solution and under quiet air conditions (fig. 1B). Tests were made later on the standard fire using different rates of application of extinguisher and under varying horizontal wind velocities (fig. 1C).

Results of Laboratory Tests

Of the data obtained, the volume of liquid required for extinguishing the fire was considered the most reliable and probably most significant indication of effectiveness. The time required for extinction paralleled rather closely the volume used but since the application was intermittent during the later stages of extinguishing (suppression of glow) the elapsed time was considered less accurate than volume of liquid used. The amounts of fuel consumed during extinguishing, as determined by the residual weights of cribs, also indicated comparative effectiveness and gave the same general conclusions as did the relative amounts of liquids used. The effectiveness of the chemical solution was expressed, for convenience, as a "superiority factor," determined by dividing the volume of water (as a standard) by the volume of chemical solution used. Values were determined separately for flame extinction and for total extinction, including both flame and glow.

The results obtained with various chemical solutions of about 25 to 30 percent concentration are shown in table 1. The effectiveness, expressed as superiority factors, ranged from less than one (less effective than water) to more than two (twice as effective as water). Examples of chemical solutions that were less effective than water are citric acid, tartaric acid, and ammonium nitrate. Examples of solutions showing two or more times the effectiveness of water for total extinction are phosphoric acid and the ammonium salts of phosphoric acid. For extinction of flame alone, the acetate, bicarbonate, and carbonate of potassium showed the highest effectiveness of the materials tested. Monoammonium phosphate which showed little superiority over water for flame extinction in quiet air, showed high superiority for both flame and total extinction in a later series of tests made under substantial wind velocities.

Boric acid, hydrochloric acid, oxalic acid, ammonium borate, ammonium oxalate, and sodium sulphate were tested also but only at substantially lower concentrations of solutions. Of these, only boric acid showed appreciable superiority over water. At 5 percent concentration, which was about the maximum obtainable with boric acid, its effectiveness compared favorably with that of phosphoric acid or of the mono- and dibasic ammonium phosphates at similar concentration. Tests were also made on combinations of two chemicals in the same solution but the results indicated no advantage over the single chemicals at the same total concentration.

With a number of the more effective chemical compounds, tests were made on solutions of lower concentration to study the relation of concentration to effectiveness. The tests were made under quiet air conditions and at the same rate of application as used in the comparative series on various chemicals. Figure 2 shows the results obtained for monoammonium phosphate, plotted to show the relation between concentration and total extinction effectiveness. It is evident that a large percentage of the superiority of the chemical solution over water is obtained with 1 to 2 percent concentrations and that the increase in effectiveness is less rapid for concentrations above 2 percent.

A third series of tests was made to study the effect of varied rates of application of extinguisher. A 10 percent solution of monoammonium phosphate was compared with water on standard fires under quiet air conditions with rates of application of from 12 to 710 cc. per minute. The actual volumes of water and chemical solution required for total extinction for rates of application within the range of 12 to 175 cc. per minute are shown graphically in figure 3. The comparison of various chemical solutions shown in table 1 was made at a rate of 26 cc. per minute. At a rate of application of about 40 cc. per minute and above, the advantage of the chemical solution over water is small and fairly constant. With lower rates of application the amount of water required for total extinction increases rapidly whereas the amount of chemical solution decreases slightly. At the lowest rate of application, more than four times as much water as 10 percent monoammonium phosphate was used for total extinction. At still lower rates it was impossible to extinguish the fire with water before the crib collapsed. This series of tests shows rather clearly that the superiority of a chemical solution over water is not a constant but is related to the rate of application of extinguisher for a relatively constant size and severity of fire.

It became evident during the course of the investigation, particularly in the field tests, that wind velocity was an important factor in extinguishing and that the relative effectiveness of chemical solutions and water might change when tested under substantial wind conditions. Consequently, late in the course of the study, some laboratory tests were made under constant and controlled, horizontal wind velocities. A 10 percent solution of monoammonium phosphate was compared with water on wood crib fires under wind velocities of 0, 2, 5, 10, and 15 miles per hour. With increasing wind velocities, it became necessary to increase the rate of application of liquid in order to extinguish the fire. The rates of application used in one series of tests were selected, after some preliminary work, to obtain approximately the same weights of crib residues (amount of fuel remaining after extinguishing). In the other series of tests a relatively high rate of application was used throughout. The results are shown in table 2 and a part are presented graphically in figure 4, in which the volumes of liquid required for total extinction are plotted against wind velocity.

It is at once apparent that the superiority of the monoammonium phosphate solution over water increases with an increase in wind velocity. With velocities of 10 and 15 miles per hour it required some 3-1/2 to 4 times as much water as chemical solution to extinguish the fire. Had it been possible to extinguish the fires with water at lower rates of application the superiority of the chemical solution would doubtless have been still larger.

This series of tests indicates that wind velocity has a major effect on the size of superiority factors of chemical solutions over water and that values obtained for the various chemicals tested in quiet air (table 1) do not apply under appreciable wind velocities. A considerable number of the chemicals tested, particularly those that showed high total (flame and glow) extinction properties, as illustrated by monoammonium phosphate, would be expected to show increased effectiveness with increased wind velocities. Apparently the flame extinction superiority of chemical is related to its glow extinction property under substantial wind velocities. Although flame may be temporarily extinguished, the glowing fuel is quickly fanned into flame again by a substantial wind, unless the chemical exhibits marked glow extinction properties. Since field fires are commonly accompanied by strong air currents, it appears that the superiority for total extinction is of much greater practical significance for most field fires than superiority in flame extinction alone.

During the progress of the investigations it was learned that Metz (4) working in Germany and using similar laboratory test procedure, had tested a group of 10 chemicals that were included in the Forest Products Laboratory tests. A comparison of the results of the two independent investigations shows a similar order of effectiveness for the 10 chemicals. Metz also found ammonium phosphate the most effective of the several materials tried.

Field Tests

The laboratory tests gave valuable indications of the comparative effectiveness of a considerable number of chemicals under rather carefully controlled conditions. In the laboratory it was possible to vary the rate of application to the size and severity of the standard fire, to approach the minimum rate and quantity required for extinction without danger of the fire getting out of control, and to apply all liquids to fires similarly and with little waste; objectives which could not be attained so well under field conditions.

The laboratory tests, however, were confined to a single type, size, and arrangement of fuel of approximately uniform moisture content. Consequently, it was considered desirable to check the laboratory results for a few of the most promising chemicals on the more important forest fuels and as much as possible in their natural arrangement and condition, by different methods of application.

A total of more than two thousand field tests were made on grass and palmetto-grass fuels of the South; hardwood leaf litter of the Appalachian region; slashings of the Lake States, Appalachian, and Pacific Northwest; logs and branches, bracken, and rotten wood of the Pacific Northwest; and pine duff and brush of California. In each of these various regions, the local Forest Service Experiment Stations and administrative units cooperated in making the field tests.

Where it was feasible and practicable, the fires were set in the fuels in their natural arrangement and condition. This was true for all tests in grass, palmetto-grass, hardwood leaf litter, pine duff, and brush. Slashings, logs and branches, bracken, and rotten wood were artificially arranged, however, either because of their nonuniform natural distribution or on account of the hazard connected with burning them in their natural arrangement under the conditions prevailing at the time of test.

Chemicals for field tests were selected on the basis of their showing in the laboratory tests. Phosphoric acid and its monoammonium and diammonium salts had shown the highest total extinction effectiveness through a wide range of concentrations. Of this group the monoammonium phosphate was used on all fuels tested in the field. Ammonium sulphate was included in the field tests on a number of fuels because of its moderate effectiveness and low cost. Either the bicarbonate or the carbonate of potassium, both of which had shown high flame extinction properties in the laboratory, was used on those fuels in which the flaming type of combustion seemed to predominate. In the later series of tests some work was done with foams. Field tests on one or more fuels were also made with calcium chloride, boric acid, phosphoric acid, and sodium acetate.

The procedure used in the field tests was modified from time to time as the work progressed, experience was gained, and additional equipment became available. For most of the tests an experimental unit, consisting essentially of a small air compressor, pressure tanks for liquids, hose and nozzles, was employed (fig. 5). A number of types of nozzles were used but the one shown in figure 6, which was adjustable over a wide range in rate of flow of liquid, was used extensively in the field tests. In some tests, back packs were used and in a few tests power pump equipment was employed. These were all included in a portable field laboratory (fig. 5) containing a variety of equipment for preparing and applying solutions and foams and taking the measurements and data required.

In the early field tests, alternate fires were extinguished with chemical solution and water, respectively. Considerable difficulty was experienced, however, in obtaining successive fires of equal severity, due to wind conditions at the time of test and to other factors. A method of making two tests simultaneously (fig. 7) -- one with chemical solution and one with water -- was finally evolved in the later experiments. This method overcame the irregularity due to wind. The two fires started at the same time were extinguished simultaneously by two operators with similar equipment, one using water and the other chemical solution. For succeeding tests, the operators alternated water and chemical solution regularly, each extinguishing the same number of fires with each liquid in a series of tests.

The data taken varied somewhat from one series of tests to the next. However, in all tests the quantities of liquids used for knocking-down the flame and mopping-up the glow, and the elapsed time occurring during extinction, were recorded. In the naturally arranged fuels, measurements were commonly made of the length of the extinguished line or the areas burned. Readings were also made of weather conditions, including temperature, relative humidity, wind velocity and direction. In some cases, moisture contents of fuels were determined.

Considerable care was exercised to have fires of comparable size and severity for extinguishing with water and chemical solution. Areas of naturally arranged fuels were selected to obtain as much uniformity as possible. Artificially piled fuels were selected to get uniform kinds and quantities of material and to have them arranged in like manner for corresponding water and chemicals fires. With all the care used, however, it was felt that large differences were common in the test fires, particularly in the naturally arranged fuels. Furthermore, no constant relation between rate of application of liquid and size of successive fires could be attained and the wind velocity and direction fluctuated considerably, both during a single test and from one fire to the next. These variations caused wide fluctuations in the results in successive tests and series of tests that were intended to be alike.

In table 3 are shown the average results obtained in the numerous field tests on different fuels with several chemical solutions and foams. The values, shown as superiority factors, are similar to those used to express the results of the laboratory tests, and represent the ratios of quantities of water and chemical solution required for total extinction of test fires. For example, a factor of 1.5 indicates that 50 percent more water was used than chemical solution in extinguishing the test fires. A range of values, as 1.2 to 1.6, indicates that the results varied as shown in different series of tests, made at different times and under somewhat different conditions.

While there are definite limitations to the data, because of nonuniform test conditions, certain important indications are nevertheless evident. Chemical solutions and foams show different results on different fuels. The flame extinguishing types of chemicals, such as the bicarbonate and carbonate of potassium, made their best showing on the flashy types of fuels, like standing grass and loose hardwood leaves, and were of little or no benefit on the glowing types of fuels, like slashings and closely compacted pine duff. On the other hand, the pronounced glow-retardant chemicals, of which monoammonium phosphate was selected as representative, were most effective on the glowing types or combinations of glowing and flashy types of fuels, such as fresh pine slashings, but showed substantially increased effectiveness over water on all fuels tried, except rotten wood. Foams were of most value on logs and branches and rotten wood, where the burning surfaces could be coated with a continuous layer of the foam. In green slashings, bracken, and similar materials, where the fuel is thick and matted, the foam cannot be applied readily to the burning surfaces and has little or no advantage over water. In general, the best results with foam were obtained when the combined foam-forming and fire-retardant chemical solutions were expelled as a liquid or as a partially expanded foam. Considering the range of fuels and concentrations of solutions tested, monoammonium phosphate was the most effective material tested; furthermore, it is moderate in cost, appears to be otherwise suitable, and is the most widely applicable.

Pretreatment Tests

Field tests were also made in which the fuels were pretreated in advance of an oncoming fire (fig. 8). These tests were made in several ways to determine the value of chemicals in holding a line from which to backfire or to act as a barrier or firebreak. Of the chemicals tried, phosphoric acid and its ammonium salts were found most effective. In pretreated strips of grass and pine duff (fig. 8C), in which the water was allowed to evaporate before test, moderately severe fires were completely stopped by the fire-retardant chemical. Lines freshly treated with monoammonium phosphate solution and from which back fires were set, were much more easily held than lines treated with water alone.

Summary

The results of both laboratory and field tests show that the extinguishing capacity of water can be increased or reinforced materially by the addition of certain chemicals, the increase depending upon both the kind of chemical and its concentration in the solution.

The superiority of a given chemical and concentration of solution over water is not a constant but varies with a number of factors of which (a) the rate of application in relation to the size and severity of the fire, (b) the wind velocity, and (c) the kind and arrangement of fuel are important. Dependent upon the conditions prevailing, the amount of chemical solution required may range from approximately the same as water to only a small part of the amount of water required to extinguish a fire.

Of the various chemicals and foams tested, monoammonium phosphate solution appears thus far to be the most practical and promising, all things considered, for most types of forest fuels.

Where an abundant supply of water is available and can be used, chemicals are not considered to have any worthwhile application. Where water is scarce or difficult to get to the fire, or where the available equipment is scarcely adequate to cope with the fire, the intelligent use of chemicals can yield important advantages. In borderline cases, chemical solution may control or hold a fire where water fails, and chemicals may, in such cases, make all the difference between success and failure in an attack upon a forest fire. The use of chemicals appears most important in the early or initial stages of attack, through the use of back packs and tankers, and they probably have little if any application on large going fires, unless for use when back firing.

It is realized that only a few of the many chemical materials and methods of application have been investigated and that further research in the field may yield valuable results. However, miraculous results with chemicals are not to be expected nor are chemicals equally effective under all forest fire conditions. Furthermore, to utilize present known fire-retarding and extinguishing chemicals efficiently, further studies are needed to develop or adapt apparatus and methods for their application. It is believed, however, that the work thus far points the way to a new and useful weapon for the forest fire fighter that will ultimately assist him in his never ending fight against fire.

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Table 1.--Extinguishing properties of concentrated water solutions of chemicals compared with water

(Tests made under quiet air conditions, liquid applied at rate of 26 cc. per minute)

Chemical	Concentration of solution by weight	Superiority factor[1] based on volumes used for-- Flame extinction	Total extinction
	Percent		
Acid, citric	25	0.90	0.75
Acid, phosphoric	26	1.50	2.40
Acid, tartaric	25	.75	.60
Aluminum sulphate	23	1.00	1.40
Ammonium carbonate	28	1.10	1.40
Ammonium chloride	28	.95	1.50
Ammonium nitrate	25	.80	.80
Ammonium nitrate	29	1.10	1.00
Ammonium phosphate, di-	26	1.30	2.10
Ammonium phosphate, mono-	26	1.20	2.00
Ammonium sulphate	26	1.10	1.70
Calcium chloride	26	1.10	1.50
Cobaltous chloride	25	1.00	1.30
Lithium chloride	27	1.25	1.80
Magnesium chloride	25	1.20	1.70
Magnesium sulphate	30	1.10	1.30
Potassium acetate	30	1.75	1.80
Potassium carbonate	25	1.90	1.70
Potassium bicarbonate	25	1.70	1.55
Potassium chloride	25	.90	1.20
Sodium acetate	27	1.50	1.60
Sodium chloride	25	1.10	1.00
Sodium phosphate, mono-	24	1.00	1.50
Sodium silicate	22	1.00	1.20
Stannous chloride	25	1.10	1.50
Zinc chloride	30	1.30	1.70

[1] Calculated by dividing the average volume of water by the average volume of chemical solution used in extinguishing similar fires.

Table 2.--Effect of wind velocity on fire extinction superiority of 10 percent monoammonium phosphate solution over water

Number of tests averaged	Wind velocity	Rate of application	Superiority factors for --		Crib residue (percent of original crib weight)	
			Flame extinction	Total extinction	Extinguishing agent: water	Extinguishing agent: chemical
	Miles per hour	Cc. per minute			Percent	Percent
5	15	120	4.5	3.3	31	38
5	10	100	4.3	3.6	32	42
5	5	60	3.3	3.7	32	42
5	2	45	2.3	3.1	31	39
5	0	21	1.3	2.1	28	34
5	15	100	5.0	4.0	18	37
5	10	100	4.3	3.6	32	42
....	0	100	1.0	1.1	47	49

Table 3.--Comparative effectiveness of chemical solutions and foams in direct extinction field tests

Extinguisher		Superiority factors[1] based on volumes of water and chemical solutions used for total extinction on --								
Chemical	Concentration	Grass	Palmetto-grass	Hardwood leaves	Pine duff	Coniferous slashings	Logs and branches	Bracken	Brush	Rotten
	Percent									
Ammonium phosphate, mono-	2.5	1.2		1.3		1.2-1.6				
	5.0	1.3-1.5	1.6	1.4		1.4-2.1				
	7.5	1.4				1.5				
	10.0	1.5		1.5	1.8	1.5-2.4	1.3-1.5	1.4	1.5	1.1
Ammonium sulphate	5.0	1.3		1.2		1.3				
	10.0	1.1	1.2	1.3	1.3	1.4-1.6				
	15.0					1.5				
Boric acid	2.5					1.2				
	4.0					1.4				
Calcium chloride	10.0			1.3		1.3				
	20.0					1.8				
Phosphoric acid	5.0	1.4								
Potassium bicarbonate	5.0	1.2			.6					
	10.0	1.4								
Potassium carbonate	5.0	1.2	1.3	1.3		1.0				
	10.0									
Sodium acetate	5.0	1.2								
Foam not loaded[2] - expelled as a liquid	9.0						1.2			
Foam loaded[2] expelled fully expanded	16.4				0.5-0.8	.7	.7			
Foam loaded[2] expelled as a liquid	16.4				1.1	1.1	1.6	1.1	1.4	1.6
Foam, Kempak (loaded)	18.8				1.2-1.5	1.3	1.3			

[1]Superiority factors calculated by dividing volume of water by volume of chemical solution used in totally extinguishing similar fires. Different procedures were employed in conducting tests on the different fuels so that the values shown are not entirely comparable in all cases.

[2]"Not loaded" foam contained only foam-forming chemicals; "loaded" foams contained approximately equal amounts of foam-forming chemicals and fire-retardant chemicals.

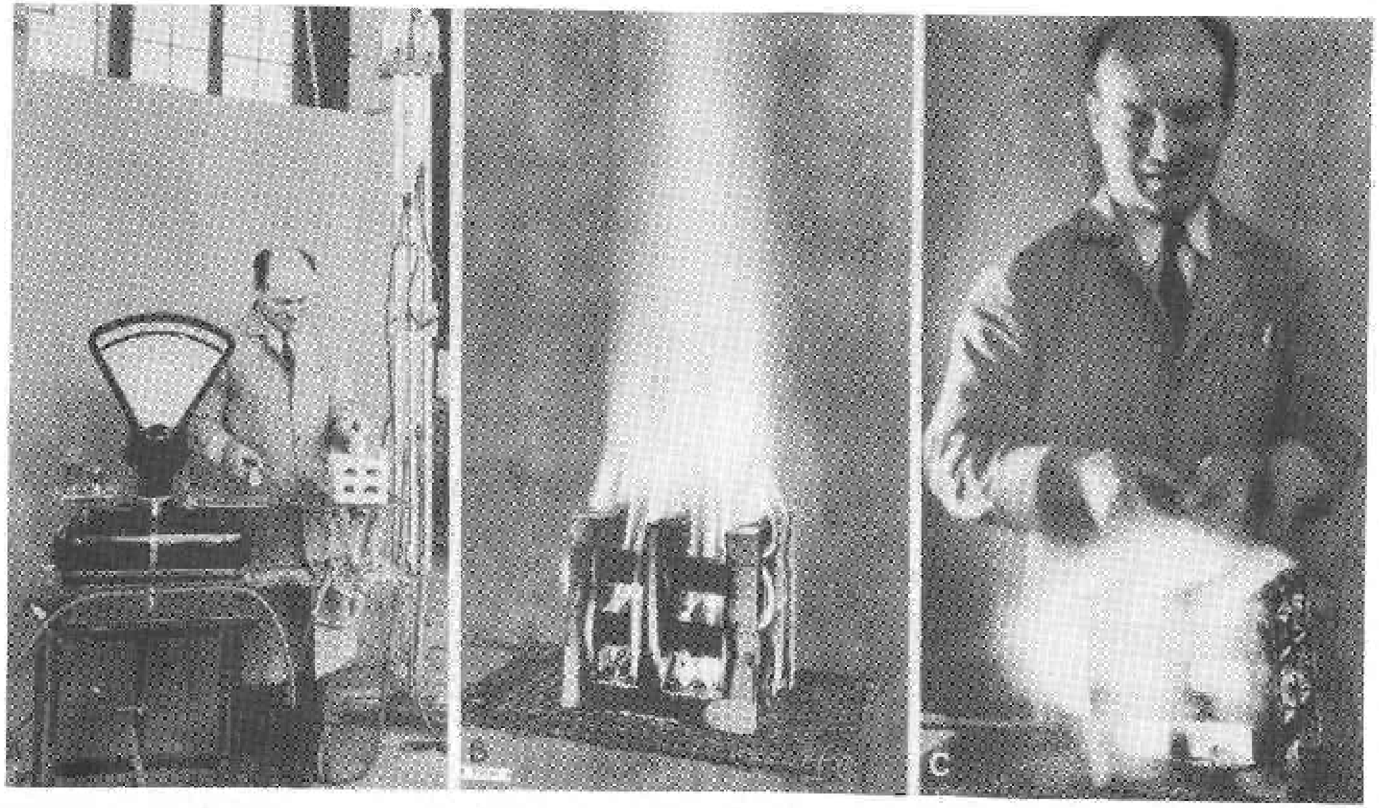

Figure 1.--A, Test assembly, showing a wood crib nearing completion, scales, battery of gas burners for igniting, and burettes for measuring volumes of extinguisher liquids. B, Appearance of crib burning in quiet air just preceding application of extinguisher. C, Early stages of extinction under a wind velocity of 10 miles per hour.

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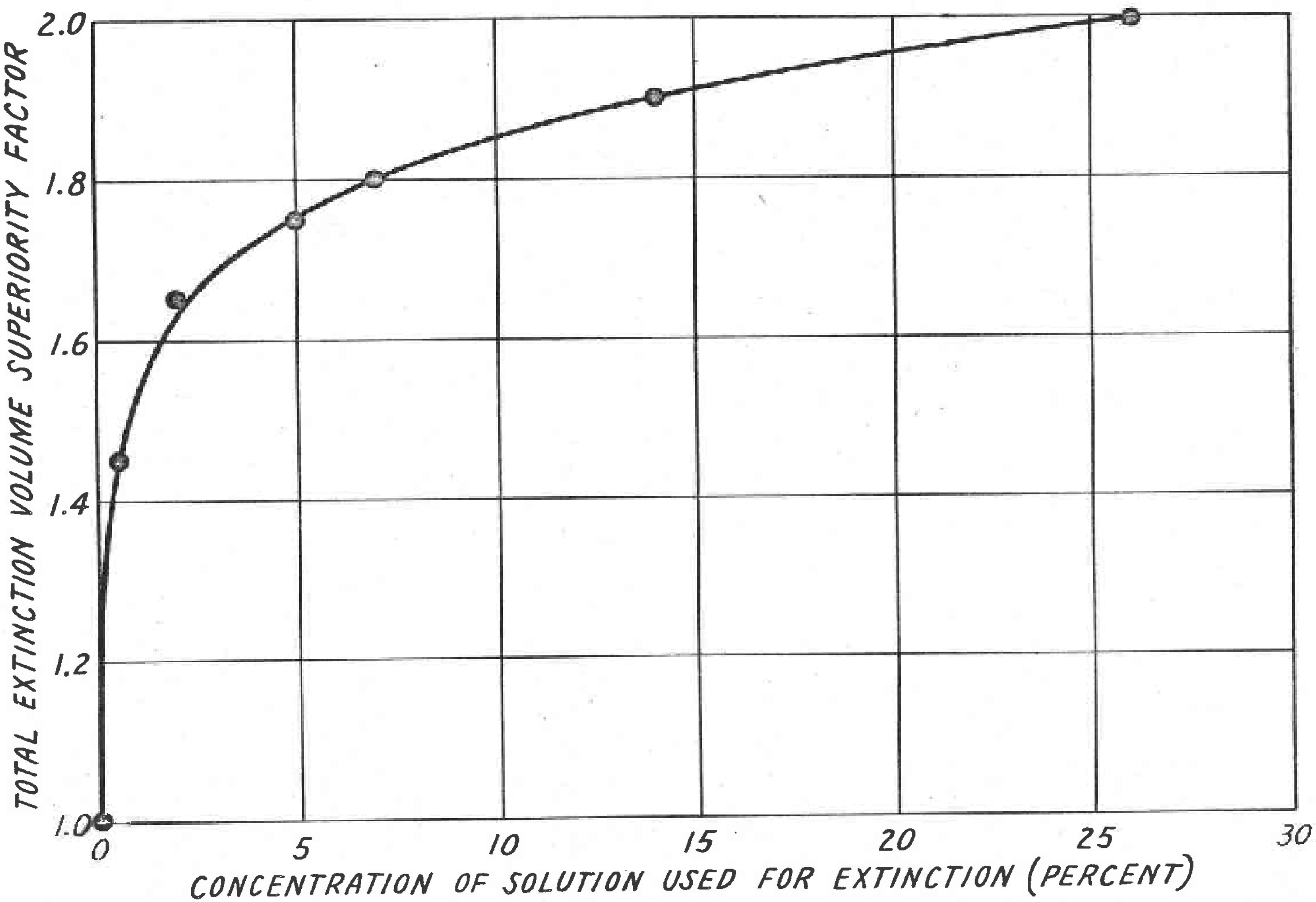

Figure 2.--Relation between total extinction volume superiority factors and the concentration of monoammonium phosphate solution.

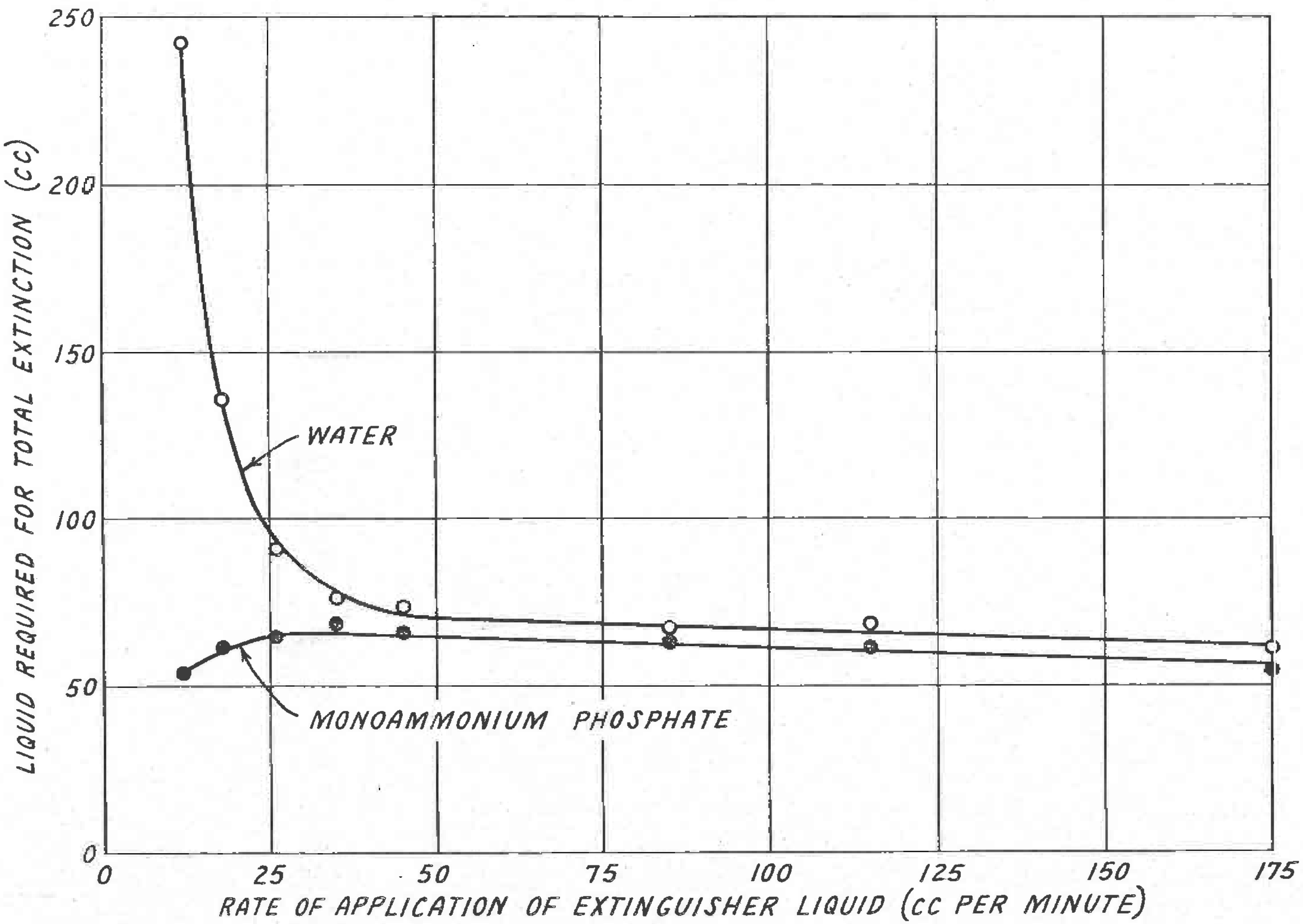

Figure 3. --The variation in volume of 10 percent monoammonium phosphate solution and water required for total extinction, with change in rate of application.

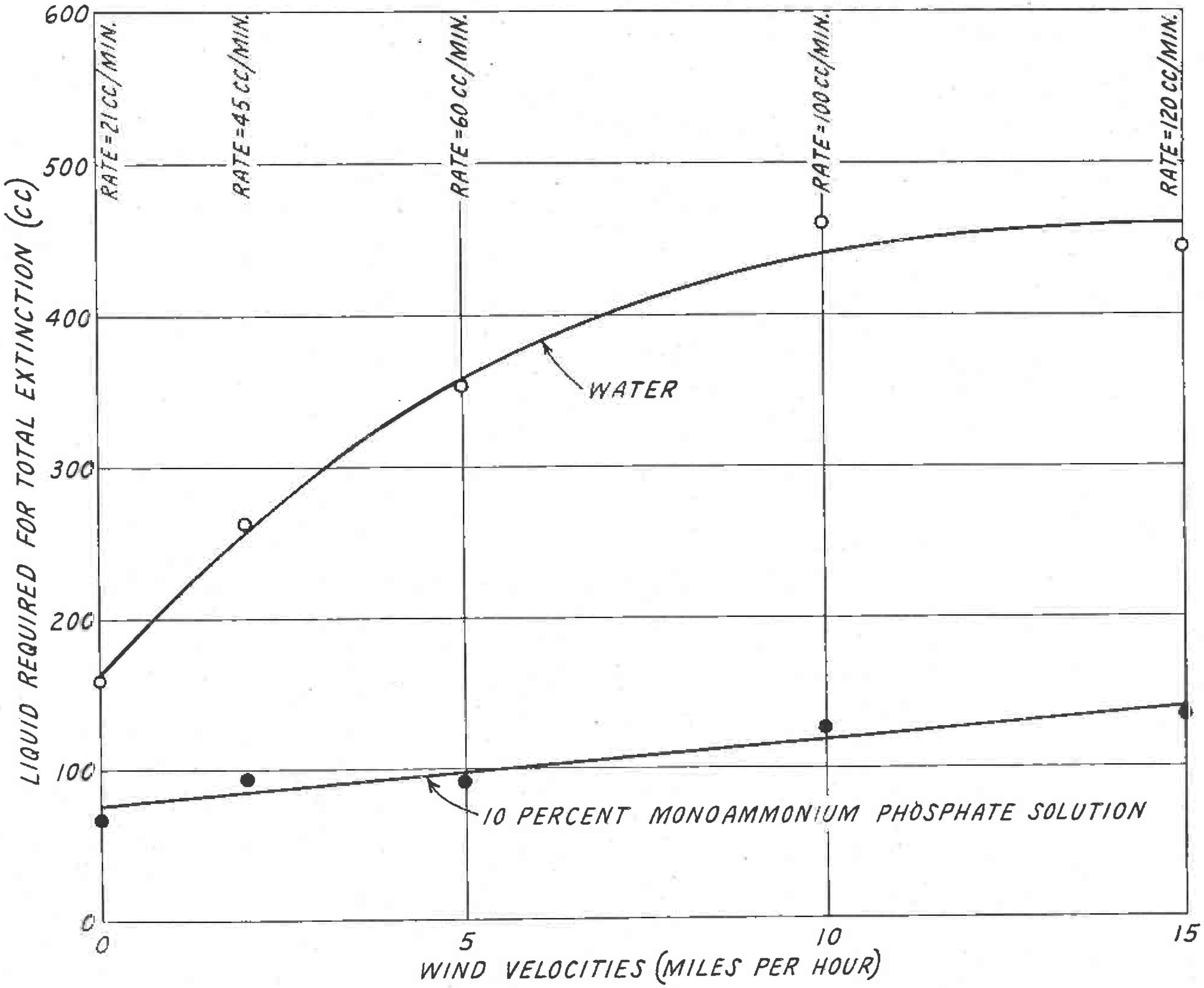

Figure 4.--Average amount of water and of 10 percent monoammonium phosphate solution required for total extinction at different wind velocities.

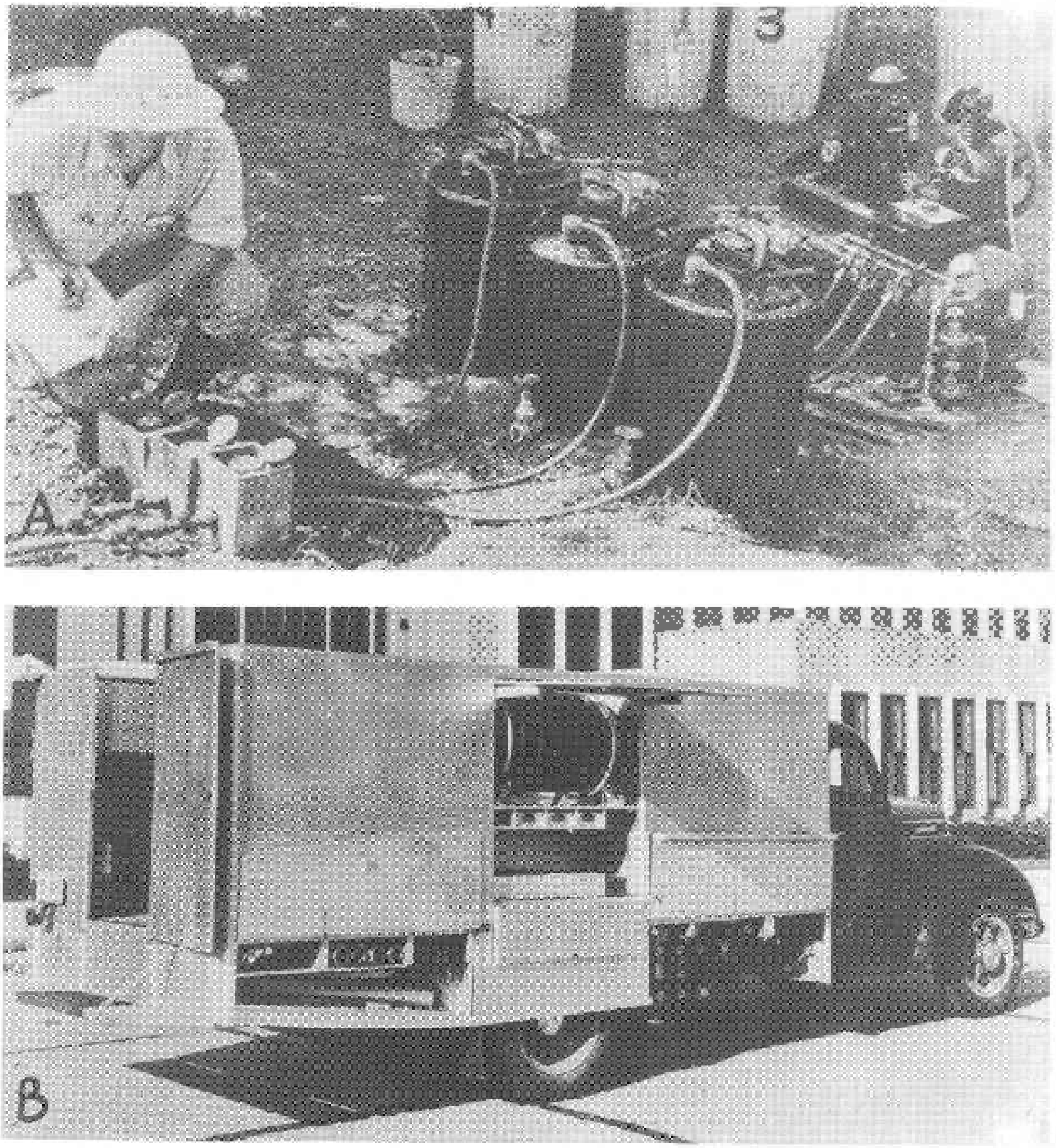

Figure 5.--Equipment used in field tests. A, Assembly of air compressor, pressure tanks for liquids, meters, and hose for making paired tests. B, Field laboratory used for housing and transportation of field equipment. In addition to numerous items of equipment the truck is provided with a three-stage centrifugal pump and three nonpressure tanks with a total capacity of 420 gallons.

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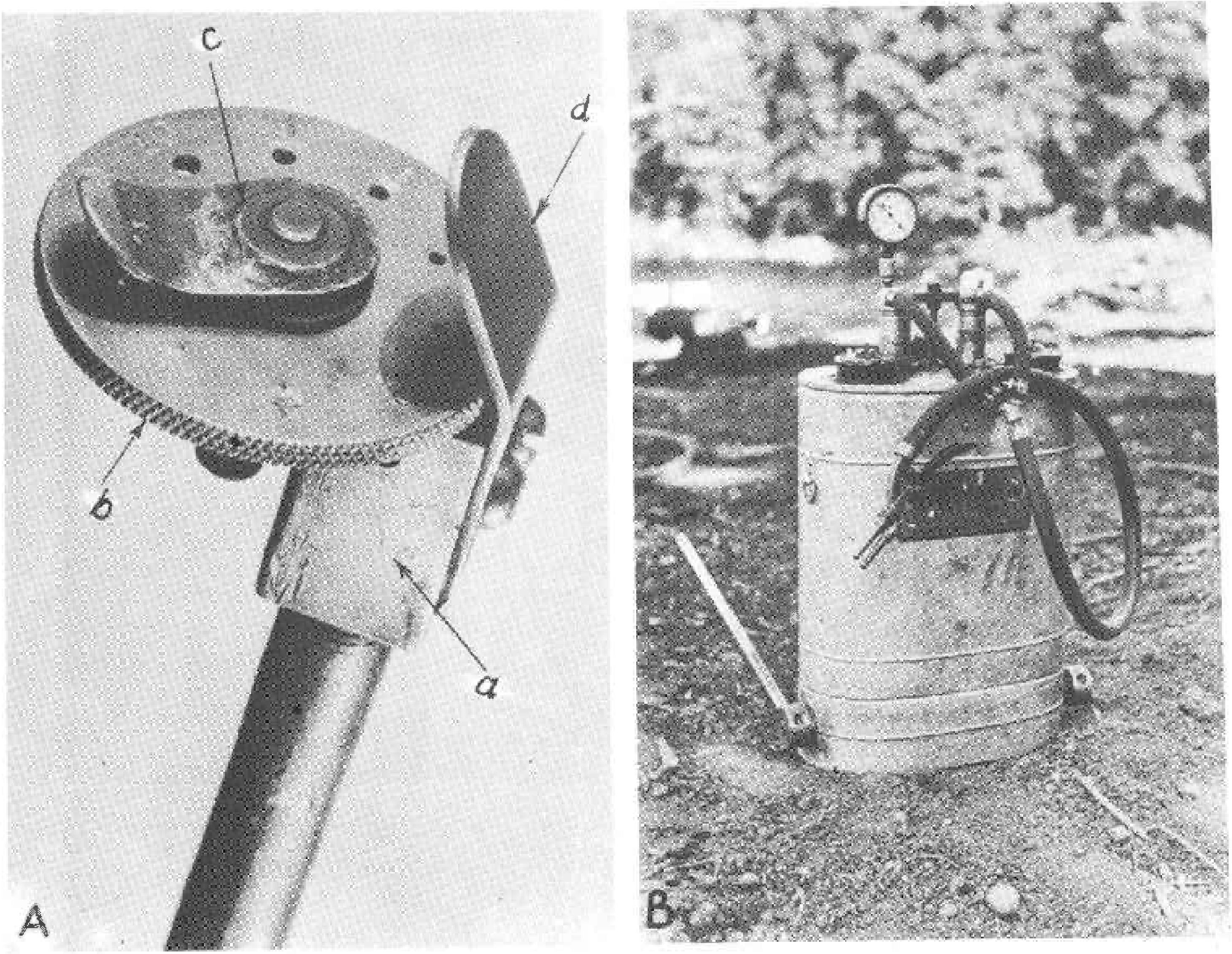

Figure 6.--A, Special nozzle designed to give a wide range in quantities of liquid applied by using the different size holes in disc B opposite opening in part A; disc quickly adjusted by means of nut C. Deflector D in position shown produces a fan-shaped spray but turned to the side permits a straight stream. B, Kempak for application of foam was used in some of the later series of tests.

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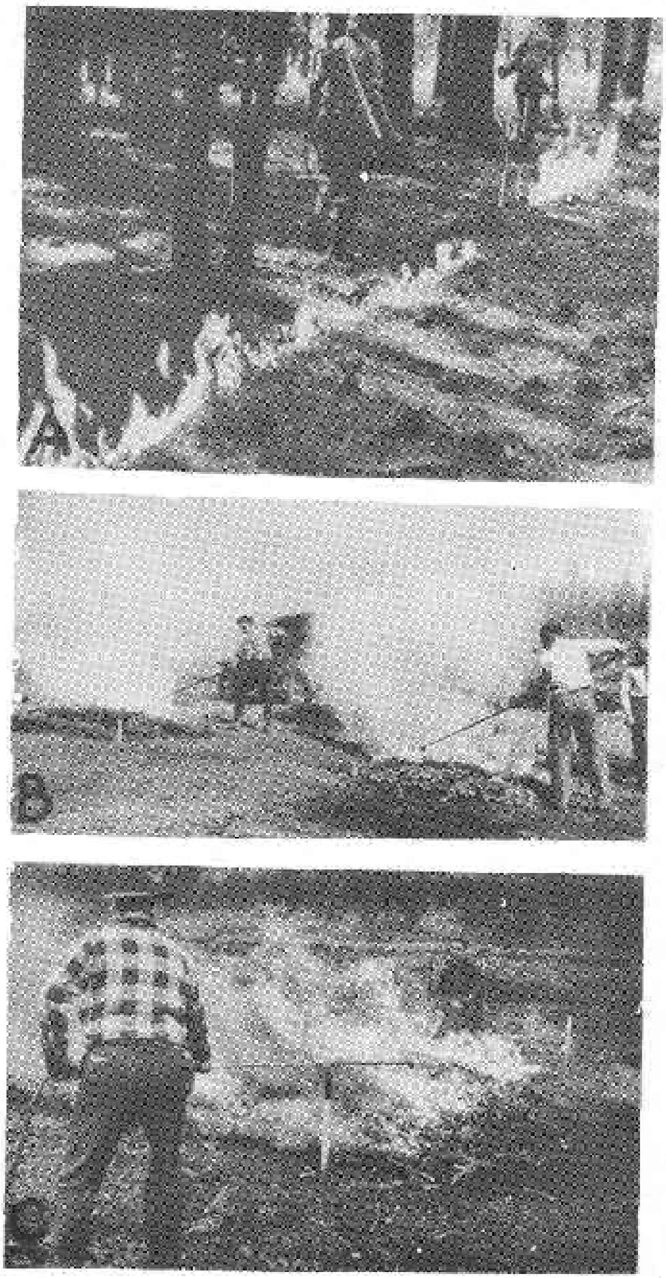

Figure 7. --A, Setting two test fires in natural pine duff. The two fires were later extinguished simultaneously -- one with water and the other with chemical solution. B, Extinguishing two test fires in piled Douglas-fir slashing. Operator on the right is using water and on the left, chemical solution. C, Extinguishing a single fire in jack pine slashings. Single fires extinguished alternately with water and chemical solution were found to give erratic results because of variable wind conditions. In later tests the paired fire system shown in "A" and "B" was used.

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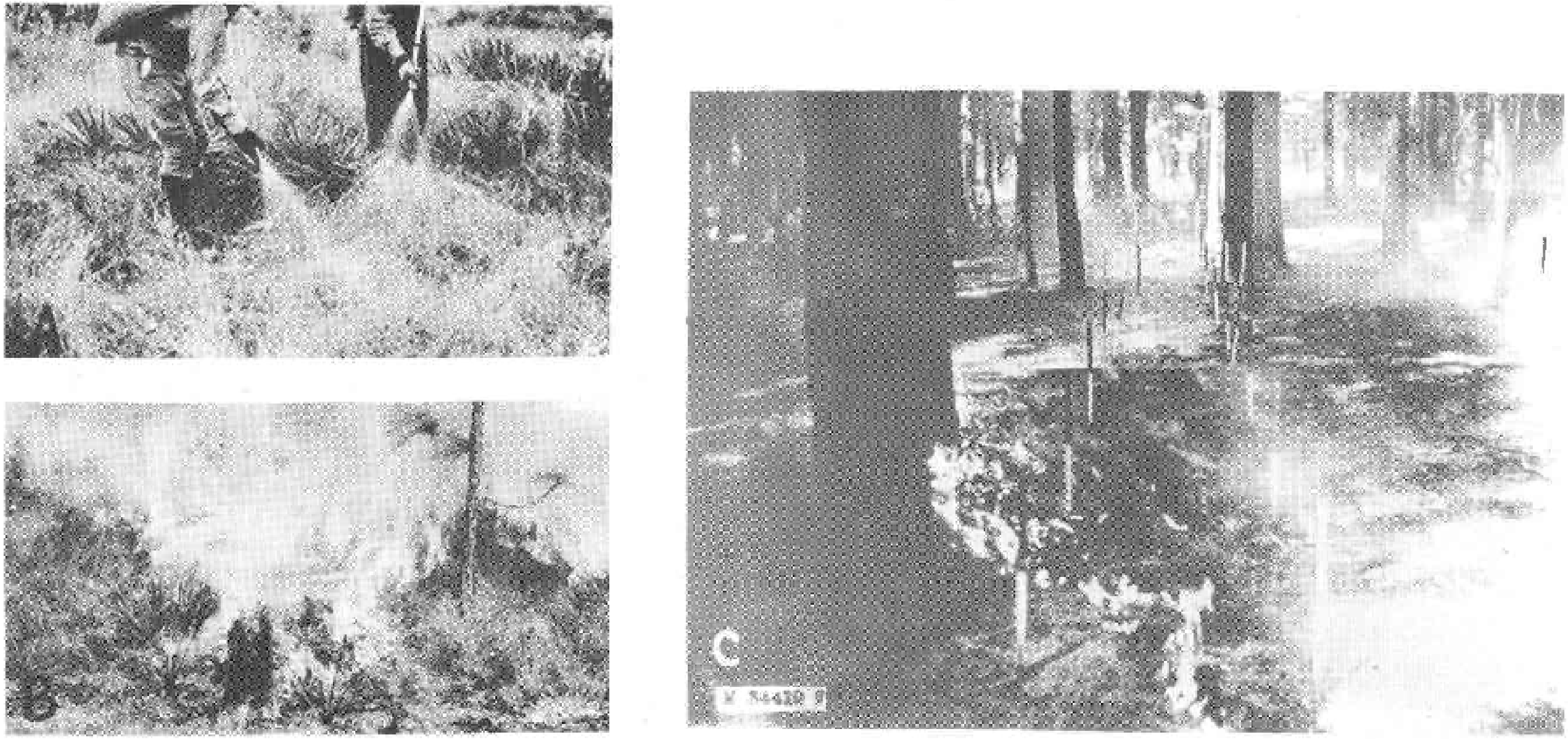

Figure 8. --A, Pretreating a line about 3 feet wide in palmetto-grass fuel with a 5 percent solution of monoammonium phosphate along which a backfire was set shortly afterwards. B, Line pretreated in "A" is on the left, backfire in the center, and main fire advancing from the right. Pretreated line held without assistance of any kind. C, Pretreatment test in ponderosa pine duff. The approximately 3-foot wide strip between the two rows of stakes was treated one day and the fire was set the following day. The strip in the foreground was treated with water and that in the background with the same quantity of 10 percent monoammonium phosphate solution per unit area. The fire burned through the water-treated strip but was stopped at the edge of the chemically-treated fuel.

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