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Fire-Extinguishing Effectiveness of Chemicals in Water Solution

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Results are presented of over eight hundred tests on wood cribs to measure the fire-extinction effectiveness of water solutions of thirty-three chemical compounds in various concentrations, and the results of similar tests with water alone.

The study indicates the advantages that may be obtained by adding chemicals to the water used. Results of several other investigators are reviewed.

RESEARCH studies were initiated in 1936 at the Forest Products Laboratory for the purpose of investigating the general chemical field for water-soluble compounds likely to be useful in forest fire control. An essential part of these studies was the developing of means for testing the relative capacities of the various chemicals to increase the fire extinction effectiveness of water. (Results of field studies based on the laboratory studies discussed in the present paper will be found in papers by Truax, *8.*) Fire-extinction tests were made using standardized wood-crib fires. Measurements were made of the extinction requirements with water and with water solutions of various chemicals. For the most part the tests were made in quiet air, although one series was carried out under horizontal wind velocities of 2, 5, 10, and 15 miles per hour.

Experimental Procedure

The test procedure was a modification of the method used by Folke (*1*) and his co-workers in investigating the factors involved in the extinction of wood fires with water. The wood cribs (Figure 1) used for the test fires were built from eighteen sticks of surfaced, clear, southern yellow pine, 1 × 1 × 6 inches (2.5 × 2.5 × 15.2 cm.) in size. Individual sticks were selected on a weight basis, from within a weight range of ± 10 per cent deviation from an average weight of 55 grams. Sticks were all conditioned to 6–7 per cent moisture content (oven-dry basis) before sorting. Precautions were taken to prevent any subsequent moisture change. Nine sticks having weights above average were matched with nine sticks having less than average weight, to make up a crib with a total weight of approximately 990 grams. In building the crib, the sticks were arranged three in a layer, six layers high. Positions of light and heavy layers were alternated, the lowest layer being built from the lighter sticks.

The test cribs were built upon a heavy wire screen laid upon extensions from one pan of a dial-reading scale (Figure 1). This arrangement made it possible to read the approximate weight continuously throughout the test. A battery of four Tirrill gas burners with wing tops to spread the flame laterally, was placed on a platform beneath the crib. The burners were lighted, and the gas pressure was quickly adjusted to a standard manometer reading. The crib was exposed to the burner flames for 1 minute. At this point the gas was shut off. When the crib had burned until it has lost 50 percent of its original weight (Figure 2), the application of liquid was started. The liquid was applied manually at a predetermined rate. Glass nozzles with capillary tube outlet tips calibrated to furnish different rates of flow at constant pressure were used for this purpose. Air pressure (2 pounds per square inch) was used to drive the liquid from a pressure buret out through flexible rubber tubing and the nozzle.

Extinguisher application continued until all visible flaming portions of the fire had been extinguished, At this point a second operator recorded the time elapsed from the start of the test and the volume of liquid consumed in extinguishing the flame. Immediately after this reading, the application was resumed and was continued until all visible glow had been extinguished. Final readings were made at this point. Time intervals were recorded for the attainment of various weight losses during the entire test.

Extinction effectiveness of water solutions of chemicals was compared with that of water done by dividing the requirements for water by the requirements for the water solution. The quotients obtained are termed "superiority factors". The most easily measured and most consistently useful criterion of chemical solution advantage over water appears to be the volume of liquid used.

Three types of tests were carried out in quiet air: (*a*) a preliminary survey to compare with water the extinction effectiveness of solutions of various chemical compounds in concentrations of 25 to 30 per cent by weight; (*b*) tests with the more effective chemicals to study the effects of variation in solution concentration; and (*c*) tests in which the rate of application of extinguisher liquid was varied.

Two types of tests were made under constant horizontal wind velocities (Figure 3). In one series the rate of application of extinguisher solution was varied in such a manner as to produce crib residues of comparable weights as the wind velocity was changed, and in the other a constant extinguisher application rate was employed, regardless of the wind velocity used.

Comparison of Chemicals

The fire-extinguishing effectiveness values obtained for the various chemicals tested in quiet air are summarized in Table I. The superiority factors given are based upon volumes of water and of chemical solution used for flame extinction and for total extinction. The several chemicals varied somewhat in their capacity to knock down flames quickly and in their ability to prevent glowing and rekindling. In quiet air, the following chemicals possess pronounced flame-extinction properties when used in concentrated solutions: potassium carbonate, potassium acetate, and potassium bicarbonate. In concentrations of 5 per cent or less, their flame-extinguishing effectiveness is considerably lower. Smaller hut distinct flame-extinction effects were found for a few other chemicals, particularly sodium acetate, phosphoric acid, the mono- and diammonium phosphates, and the chlorides of zinc and lithium. The following agents revealed pronounced total-extinction properties, even in solutions of 2 per cent concentration: phosphoric acid, diammonium phosphate, monoammonium phosphate, and boric acid. Ammonium sulfate, lithium chloride, magnesium chloride, potassium acetate, potassium carbonate, and zinc chloride showed lower hut distinct total-extinction effectiveness in concentrated solutions.

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TABLE I. EXTINCTION SUPERIORITY OF CHEMICAL SOLUTIONS OVER WATER WHEN TESTED IN QUIET AIR

(Application rate, 26 cc. per minute)

No. of Tests Made	Extinguishing Agent	Concn. % by Weight	Vol. Superiority Factor Flame	Vol. Superiority Factor Total
5	Boric acid	5.0	1.15	1.80
6		2.0	1.10	1.60
8		1.0	1.10	1.65
8		0.5	1.10	1.50
10	Citric acid	25.0	0.90	0.75
10	Hydrochloric acid	5.0	1.00	1.15
6	Oxalic acid	8.8	0.80	0.80
9	Tartaric acid	25.0	0.75	0.60
5	Phosphoric acid	75.0	1.25	1.90
4		26.0	1.50	2.40
5		5.0	1.10	1.75
5		2.0	1.10	1.70
6		0.5	1.05	1.50
10	Ammonium borate	10.0	0.90	1.25
10		5.0	1.00	1.40
3	Ammonium carbonate	28.0	1.10	1.40
4		14.0	1.00	1.30
3	Aluminum sulfate	23.0	1.00	1.40
3	Ammonium chloride	28.0	0.95	1.50
11	Ammonium nitrate	25.0	0.80	0.80
3	Ammonium nitrite	29.0	1.10	1.00
10	Ammonium oxalate	5.0	0.90	0.90
4	Diammonium phosphate	26.0	1.30	2.10
4		14.0	1.20	1.90
4		7.0	1.10	1.75
10		5.0	1.10	1.80
10		2.0	1.10	1.70
4		0.5	1.10	1.60
Av. of 2 series; total no. tests, 126	Monoammonium phosphate	26.0	1.20	2.00
		14.0	1.30	1.90
		7.0	1.30	1.80
		5.0	1.20	1.75
		2.0	1.20	1.65
		0.5	1.10	1.45
5	Ammonium sulfate	26.0	1.10	1.70
5		9.0	1.10	1.70
5		5.0	1.00	1.60
5		3.0	1.00	1.50
5		0.5	1.00	1.40
10	Cobaltous chloride	25.0	1.00	1.30
10		5.0	0.90	1.10
3	Calcium chloride	26.0	1.10	1.50
3	Lithium chloride	27.0	1.25	1.80
3	Magnesium chloride	25.0	1.20	1.70
10	Magnesium sulfate	30.0	1.10	1.30
10	Potassium acetate	30.0	1.75	1.80
7		5.0	1.30	1.50
3	Potassium bicarbonate	25.0	1.70	1.55
5		14.0	1.50	1.70
4	Potassium carbonate	25.0	1.90	1.70
9		13.0	1.50	1.75
9		5.0	1.25	1.40
5		2.0	1.20	1.10
5		1.0	1.10	1.00
3	Sodium acetate	27.0	1.50	1.60
5		5.0	1.20	1.30
6		3.0	1.20	1.20
8		1.0	1.20	1.10
2	Potassium chloride	25.0	0.90	1.20
4	Monopotassium phosphate	18.0	0.95	1.35
3	Sodium chloride	25.0	1.10	1.00
4	Monosodium phosphate	24.0	1.00	1.50
2	Sodium silicate	22.0	1.00	1.20
10	Sodium sulfate	6.0	1.00	1.00
10	Stannous chloride	25.0	1.10	1.50
10		5.0	1.00	1.20
10	Zinc chloride	30.0	1.30	1.70
10		10.0	1.10	1.45
10		5.0	1.10	1.30
10		2.0	1.05	1.30
5	Monoammonium phosphate + boric acid (1:1)	5.0	1.10	1.70
4	Monoammonium phosphate + potassium carbonate (1:2)	26.0	1.05	1.10
5	Monoammonium phosphate + potassium carbonate (1:1)	5.0	1.10	1.35
2	Borax + boric acid (2:1)	14.0	1.10	1.40
5	Borax + boric acid (1:2)	14.0	1.10	1.70
4	Boric acid + potassium carbonate (1:5)	25.0	1.40	1.60
5	Boric acid + sodium acetate (1:2)	27.0	1.10	1.20
	Boric acid + sodium acetate (1:1)	5.0	1.10	1.20

Effect of Concentration of Chemical

The relation of concentration to effectiveness of phosphoric acid and its primary and secondary ammonium salts is shown in Figure 4. For a concentration lower than about 2 per cent by weight, the superiority of the solution over water increases rapidly with the concentration. Above this point the increase in effectiveness becomes much less in proportion to further increase in concentration. Thus, 2 per cent solutions of these chemicals possess a major portion of the extinction advantage possessed by solutions of much higher concentration. This may be true of various other chemicals.

Effect of Rate of Application

The third type of test in quiet air involved a series comparing 10 per cent monoammonium phosphate solution and water as extinguishers, at rates of application varying from 12 to 710 cc. per minute. The volume superiorities for the chemical solutions at each rate of application are given in Table II. Figure 5 affords direct comparisons of average volumes of water and water solution used (data from Table IV). Superiority factors expressing advantage in time required for extinction with the chemical solution, and advantage measured by relative weights of crib residues at the completion of extinction (Table IV), revealed similar trends with changing rates of application, but the volume superiority factors were the most consistent of these criteria.

TABLE II. EXTINCTION SUPERIORITY AND VOLUME OF 10 PER CENT MONOAMMONIUM PHOSPHATE SOLUTION COMPARED WITH WATER AT VARIED RATES OF APPLICATION OF LIQUID IN QUIET AIR

No. of Tests Made	Rate of Application, Cc./Min.	Vol. of Soln., Cc. Flame extinction	Vol. of Soln., Cc. Total extinction	Vol. of Water, Cc. Flame extinction	Vol. of Water, Cc. Total extinction	Vol. Superiority Factor for Chemical Soln. Flame extinction	Vol. Superiority Factor for Chemical Soln. Total extinction
21	710	60.3	62.2	57.8	65.5	0.96	1.05
21	440	57.8	61.7	62.0	65.0	1.07	1.05
20	310	51.6	57.7	54.7	61.1	1.06	1.06
20	175	50.7	53.8	57.0	61.1	1.12	1.13
20	115	60.0	60.8	63.9	68.2	1.06	1.12
21	85	62.0	63.0	63.7	67.4	1.03	1.07
20	45	65.5	66.0	70.3	74.0	1.07	1.12
20	35	67.8	68.2	68.8	76.2	1.02	1.12
20	26	63.0	64.3	65.9	91.2	1.05	1.42
20	18	58.6	61.9	61.6	135.8	1.05	2.19
13	12	43.9	54.0	56.0	242.0	1.28	4.48

This test series revealed slight differences in the amounts of monoammonium phosphate solution required at the different rates of application, but a decided increase (Figure 5) in the amount of water required for accomplishing extinction, as the rates of application approached the minimum rate at which extinction could be accomplished with water.

Effect of Wind Velocity

A chemical compound in a given concentration in water may possess quite different fire-extinction behaviors under zero wind velocity conditions and under appreciable velocities. Data of the first group in Table III indicate that with an application rate of 100 cc. per minute (a relatively high rate of application) factors up to 4 or 5 can be realized for the supriority of 10 per cent monoammonium, phosphate solution over water at wind velocities of 10 or 15 miles per hour. Furthermore, the crib residues after extinction were considerably larger with the chemical solution than with water in the tests made under appreciable wind velocities.

In further tests the rates of application of extinguisher were varied in such a manner as to follow fairly closely the minimum

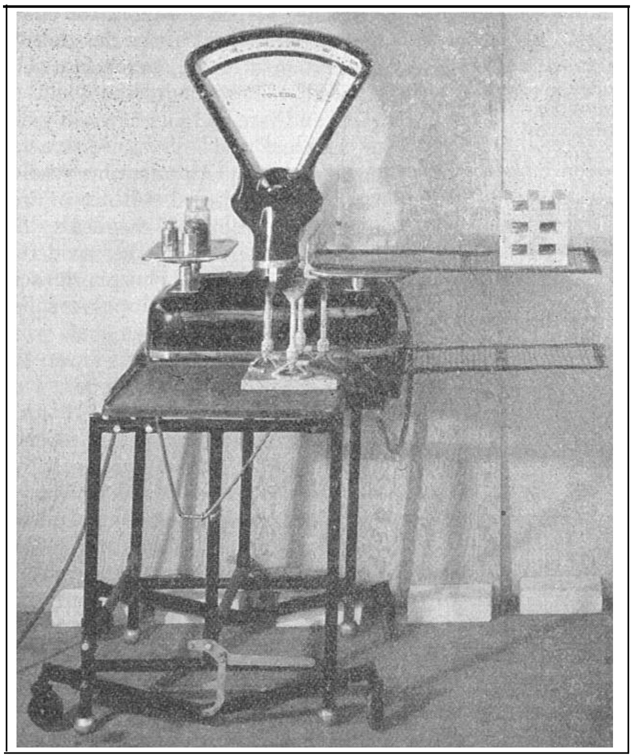


FIGURE 1. TEST ASSEMBLY, SHOWING A WOOD CRIB BEFORE IGNITION, SCALE, AND BATTERY OF GAS BURNERS FOR IGNITING

rate of application requirements for water, as the intensity of the standard test fire increased with the higher wind velocities. In these tests more nearly comparable work was done in extinction, as measured by crib residues. Data from these tests are given in the second group in Table III. Here the extinguishing advantage is influenced by both the variation in wind velocity and the change in rate of application of extinguisher liquid.

An additional point brought out by the tests of Table III is the fact that, under sizable wind velocities, a primarily glow-retarding agent may become an effective flame-checking agent. In several cases in the data cited, flame-extinction superiority factors surpass those for total extinction. In the tests in quiet air the flame-extinction advantage was smaller than the total-extinction one.

Comparison with Results of Other Investigators

The results obtained and the general tendencies indicated in the Forest Products Laboratory tests appear to be compatible and in concurrence with the results of other investigators working along similar or related lines.

Folke and eo-workers (*1*) studied in detail the factors involved in the extinction of wood fires with water. As criteria for determining the most effective rates of application for water, Folke considered crib residue weights and the volumes of liquid required for total extinction. The Forest Products Laboratory tests involved the same two criteria, but in addition, the volumes required for flame extinction and for total extinction were measured separately. Results of Folke and of the Forest Products Laboratory, for varied rates of application, are compared in Table IV.

Metz (*3*) compared the effectiveness of water and water solutions of various chemicals in extinguishing burning wood cribs by measuring the volumes of liquid required for total extinction. The wood cribs employed by Metz were about eight times the size of those used by the Forest Products Laboratory. His test fires were all extinguished under a horizontal wind velocity of about 6.7 miles per hour.

TABLE III. INFLUENCE OF WIND VELOCITY UPON EXTINCTION SUPERIORITY OF 10 PER CENT MONOAMMONIUM PHOSPHATE SOLUTION COMPARED WITH WATER

Group	Wind Velocity, Miles/Hr.	Rate of Application, Cc./Min.	Vol. Superiority Factors: Flame extinction	Vol. Superiority Factors: Total extinction	Crib Residue, % of Original Crib Weight: Extinguishing agent: water	Crib Residue, % of Original Crib Weight: Extinguishing agent: chemical
1	15	100	5.00	4.0	18	37
	10	100	4.30	3.6	32	42
	0	100	1.00	1.1	47	49
2	15	120	4.50	3.3	31	38
	10	100	4.30	3.6	32	42
	5	60	3.25	3.7	32	42
	2	45	2.30	3.1	31	39
	0	21	1.30	2.1	28	34

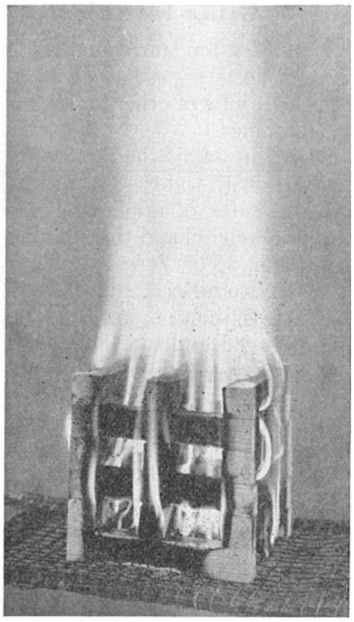
In Table V volume superiority factors for total extinction, calculated from the data of Metz, are compared with factors derived from the Forest Products Laboratory tests in quiet air. Trends appear generally similar, but the superiorities obtained by Metz are larger. This is attributed primarily to the difference in wind conditions.

Certain studies have been made of the effect of chemicals upon the destructive distillation products of wood; while not

TABLE IV. RATES OF APPLICATION OF EXTINGUISHER LIQUID, VOLUMES REQUIRED FOR TOTAL EXTINCTION, AND WEIGHTS OF CRIB RESIDUE IN FOREST PRODUCTS LABORATORY AND FOLKE TESTS

F. P. L. Tests, 990-Gram Wood Cribs							Folke Tests, 840-Gram Wood Cribs			
	Extinguishing Agent							Extinguishing Agent, Water		
	Water			10% Monoammonium Phosphate						
Rate of Application of Agent, Cc./Min.	No. tests made	Quantity used, cc.	Residue[a] remaining after extinction, %[b]	No. tests made	Quantity used, cc.	Residue[a] remaining after extinction, %[b]	Rate of Application of Agent, Cc./Min.	No. tests made	Quantity used, cc.	Residue[a] remaining after extinction, %[b]
...	1	0.0	4.0	..	..	..	..	..	...	..
12	3	242.0	9.1	10	54.0	30.8	4	1	104	6.8
18	10	135.8	29.7	10	61.9	34.1	8	1	164	9.2
26	10	91.2	37.0	10	64.3	38.8	13	1	161	20.6
35	10	76.2	41.6	10	68.2	41.8	17	2	135	29.0
45	10	74.0	43.5	10	66.0	44.6	21	1	69	41.0
85	11	67.0	47.9	10	63.0	48.5	26	2	66	44.2
115	10	68.2	48.6	10	60.8	49.5	..	..	...	..
175	10	61.1	49.3	10	53.8	49.8	..	..	...	..
310	10	61.1	50.4	10	57.7	50.5	..	..	...	..
440	11	65.0	..	10	61.7	..	..	..	...	..
710	11	65.5	..	10	62.2	..	..	..	...	..

[a] No weight corrections were made for applied water or solution that remained on the fuel.
[b] Residue weight percentages are based upon the weight of the original crib in each case.



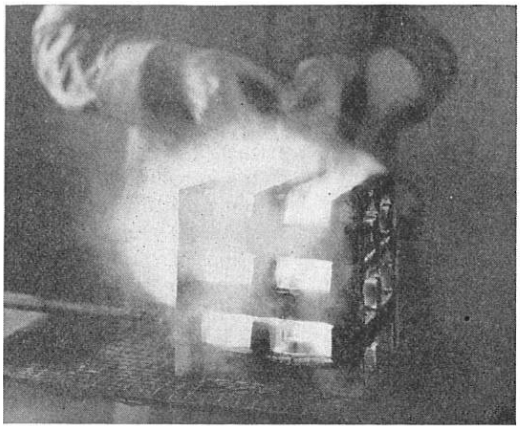


FIGURE 2 (*Left*). CRIB BURNING IN QUIET AIR JUST BEFORE APPLICATION OF EXTINGUISHER
FIGURE 3 (*Below*). BEGINNING OF EXTINCTION UNDER A WIND VELOCITY OF 10 MILES PER HOUR

aimed at the extinguishing of fires, they throw light on the question of how suitable chemicals can increase the effectiveness of water as an extinguishing agent, a question which will he discussed later.

Richardson (5) investigated the relative capacities of eighteen different chemical compounds to increase charcoal yields from standardized sawdust samples mixed with the agent and heated for 30 minutes at 450° C. in the absence of air. He obtained substantial differences in the amounts of charcoal residue. The charcoal yields of Richardson can be calculated to superiority factors by dividing the yields obtained with chemical treatment by those obtained with water treatment. while these superiority factors are not directly comparable with the volume superiority factors for total extinction in the Forest Products Laboratory tests, it is interesting to note the parallelisms evident in Tables VI and VII.

TABLE V. TOTAL EXTINCTION SUPERIORITY OF CHEMICAL SOLUTIONS OVER WATER, BASED ON RESULTS FROM FOREST PRODUCTS LABORATORY AND FROM METZ

	F. P. L. Tests		Metz Tests	
Extinguishing Agent	Concentration, %	Vol. superiority factor	Concentration, %	Vol. superiority factor
Diammonium phosphate	26	2.1	27	3.40
Ammonium sulfate	26	1.7	44	2.80
Sodium acetate	27	1.6	27	1.15
Ammonium chloride	28	1.5	25	2.40
Calcium chloride	26	1.5	21	2.30
Ammonium carbonate	28	1.4	24	1.20
Sodium chloride	25	1.0	26	1.20

TABLE VI. RELATIVE EFFECTIVENESS OF CHEMICALS IN FOREST PRODUCTS LABORATORY AND RICHARDSON TESTS

Extinguishing Agent[a]	Vol. Superiority Factor (F. P. L.)	Charcoal-Yield Superiority Factor (Richardson)
Monoammonium phosphate	2.00	1.70
Magnesium chloride	1.70	1.53
Ammonium sulfate	1.65	1.88
Zinc chloride	1.65	1.56
Ammonium chloride	1.50	1.86
Calcium chloride	1.50	1.37
Sodium chloride	1.00	1.11
Water	1.00	1.00

[a] 25 per cent solutions used in F. P. L. tests; 0.8 gram chemical to 4 grams wood used by Richardson.

Palmer (*4*), in studying the effect of phosphoric acid in the destructive distillation of wood, reported a substantial reduction in the yield of gases and tars and an increased yield of charcoal and pyroligneous acid, mostly water. Although his studies were not concerned with the fire retarding action of chemicals, his findings constitute further evidence as to the action of phosphoric acid (and its readily decomposed salts) in reducing the amount of volatile combustible products from the thermal decomposition of wood.

Thomas and Hochwalt (*7*) atomized water solutions of a number of chemicals on standardized gasoline test fires. The extinction effectiveness was expressed in terms of the smallest solution concentrations capable of extinguishing the fire. Their conditions of test and measurement of results are not comparable to the extinguishing tests described in this paper, but some of the potassium salts that gave best results in their tests also showed good results as flame extinguishers in the wood-crib tests.

Role of Chemical Compounds in Fire Extinction

The main effect of water in extinguishing fire in solid fuels is the cooling of the seat of the fire below the ignition point of the fuel; another effect is usually included in describing the action of water on a fire (the dilution of combustible gases by the steam), but under most conditions this is probably of minor importance. Whatever the relative importance of these two effects, it would not be expected that the addition of inorganic salts to water would improve its characteristics with respect to either of them because they are dependent on two inherent properties of the water little affected by additions –viz., the heat of vaporization and the liquid-vapor volume ratio. Any improvement in the fire-extinguishing properties of water by the addition of inorganic salts must be effected through the influence of the additions on the rate of combustion.

In this connection, differentiation must be made between at least two primary types of fires–the flashy-burning and the heavy-glowing types. The standardized gasoline fires employed by Thomas and Hochwalt (*7*) in their studies of extinction by water solutions of certain chemicals clearly belong to the former type. In the burning of very rotten dry wood, for instance, the heavy-glowing type is encountered almost entirely. In the combustion of normal wood, both types are encountered. The first type predominates during the flaming

TABLE VII. EFFECTIVENESS OF DIFFERENT CONCENTRATIONS OF MONOAMMONIUM PHOSPHATE IN FOREST PRODUCTS LABORATORY AND RICHARDSON TESTS

F. P. L. Tests		Richardson Tests	
Concentration, %	Vol. superiority factor	Grams salt/100 grams wood	Charcoal-yield superiority factor
..	..	50.00	1.77
26.0	2.00	20.00	1.70
14.0	1.90	15.00	1.66
7.0	1.80	10.00	1.60
5.0	1.75	5.00	1.53
2.0	1.65	2.50	1.45
0.5	1.45	1.25	1.38
0.0	1.00	0.00	1.00

stages of combustion, and the second type during the later heavy-glowing period. Principal combustion in the first stage occurs at some little distance outside the wood surface, whereas in the second stage the seat of fire is within the wood surface.

In view of these distinctions, it is not surprising that, while Thomas and Hochwalt found such agents as potassium acetate, potassium carbonate, and potassium bicarbonate very effective in the extinction of gasoline fires, the Forest Products Laboratory wood-crib fire-extinction tests revealed for these salts marked flame-extinction properties only.

The principal function of both fire-proofing and fire-extinguishing agents is to retard combustion. A distinct parallelism is found between such agents, and a similarity in the mechanism through which the results are accomplished reasonably may be assumed. A discussion of these mechanisms is as relevant to extinction as to retardation.

Since the time of Gay-Lussac (*2*) the commonly accepted explanation of the effect of fire-proofing agents has been that they retarded the rate of combustion by either or both of two mechanisms: (*a*) by diluting the combustible gases with noncombustible decomposition products, and (*b*) by forming a protective glaze over the surface of the fuel. The first of these has been considerably overrated because no salt in practical amounts gives off a large volume of noncombustible gas in comparison with the volume of noncombustible gases and vapor produced by the thermal decomposition of wood. The second mechanism is a reasonable one for some cases, since it is confirmed by the known melting point of some of the effective salts or of their thermal decomposition products. But these explanations have not been satisfactory for all the effective agents.

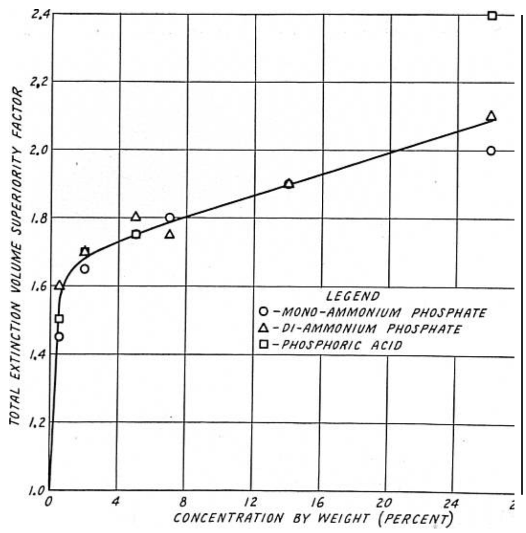


FIGURE 4. TOTAL EXTINCTION EFFECTIVENESS OF PHOSPHORIC ACID AND MONO- AND DIAMMONIUM PHOSPHATES

More recently a third mechanism has been described that accounts for the effectproduced by certain agents that do not clearly fall in the other two groups and that even may he the most important mechanism through which all the fire-proofing agents obtain their effects. Results of Metz (*3*), Serebrennikov (*6*), Richardson (*5*), and Palmer (*4*) indicate that many of the agents effective in fireproofing or extinction modify the thermal decomposition of wood in that smaller amounts of the volatile combustibles, gas and tar, are formed with correspondingly larger amounts of the nonvolatile charcoal. The surface layer of charcoal is less readily combustible than the gas and tar, and hence the rate of combustion is slowed down. According to Metz, the charcoal layer also slows down the thermal decomposition of the wood underneath.

In order to have high effectiveness in extinguishing wood fires, chemical solutions must be able to stop the glowing and the reignition of the fuel, as well as to knock down the flames. Water, when available in sufficient quantities to "drown" the fire will do both; but when applied in limited quantities, the water may be evaporated and still leave enough heat to permit reignition of the hot mass of residual fuel. The addition of a good fire-retardmg chemical to the water adds something that reduces the amount of combustible material thrown off by the hot fuel and, even after the water has all evaporated, reduces the amount of glowing and the tendency to reignite.

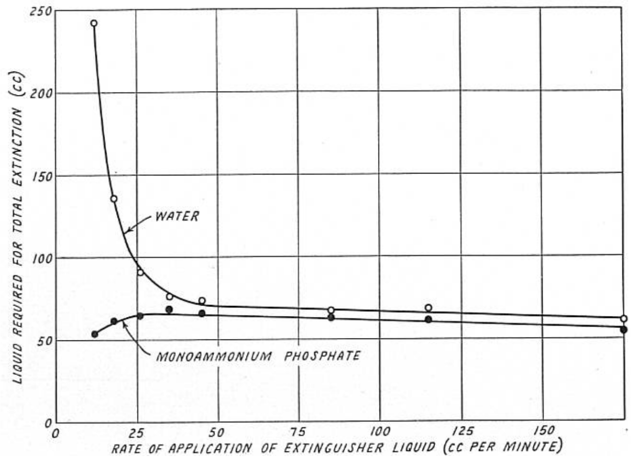


FIGURE 5. VARIATION IN VOLUME OF 10 PER CENT MONOAMMONIUM PHOSPHATE SOLUTION AND WATER REQUIRED FOR TOTAL EXTINCTION, WITH CHANGE IN RATE OF APPLICATION

Thus, flame-extinguishing properties alone may he sufficient in controlling a gas or vapor fire, but ability to extinguish glowing and to prevent reignition is of greater importance in extinguishing a mass of glowing solid fuel.

Conclusions

The experimental results obtained at the Forest Products Laboratory using water solutions of chemicals to extinguish standard test fires indicate the following:

1. The superiority of a given concentration of a given chemical compound in water, over water alone, varies with both the rate of application of the liquid and the wind velocity.
2. As extinenisher-solution application rates approach the minimum rate at which extinction can be accomplished with water, the amount of water required increases greatly whereas the amount of a 10 per cent monoammonium phosphate solution required remains approximately constant.
3. The superiority of a 10 per cent monoammonium phosphate solution over-water is greater with moderate wind velocities (up to 15 miles per hour) than at zero wind velocity.
4. Several of the most effective agents in concentrations of about 2 per cent possess a large part of the extinction effectiveness atained with much higher concentrations.
5. Chemicals vary in their capacity to knock down flames quickly and in prevention of glowing and rekindling. Potassium acetate, potassium bicarbonate, and potassium carbonate have pronounced flame-extinguishing capacity. Phosphoric acid, di- and monoammonium phosphates, and boric acid have pronounced glow-extinguishing and total-extinguishing capacity.
6. A survey of the results and theories of other investigators indicates that the fire-retarding action of chemicals is related to both physical and chemical properties. For the effective agents studied, possession of one or both of the following capabilities seems to be important: (*a*) reduction of the volume of com-

bustible gas formed (by increasing the proportion of charcoal formed); (*b*) formation of a fused inactive surface-protective layer upon the combustible surface. Cooling the seat of the fire, the smothering action of liberated, inert gas, and catalytic action may be contributing factors, but their importance seems very limited.

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