EXPERIMENTS IN FIREPROOFING WOOD

Fifth Progress Report

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EXPERIMENTS IN FIREPROOFING WOOD -- FIFTH PROGRESS REPORT[1]

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Four previous progress reports[3] have been presented to this Association, giving details of experimental work in progress at the Forest Products Laboratory in a study of the fire resistance of wood impregnated with various chemicals. Included in those reports were discussions of methods used and conditions affecting results, test data on various single chemicals and combinations of chemicals, groupings of chemicals as related to their effectiveness, and an attempted correlation of some of the properties of chemicals to their fire-retarding characteristics. The present report contains further results obtained since the last report was issued, and a summary of the results reported in this and previous reports.

About 130 single chemicals or combinations of chemicals have been studied in a preliminary way. Of these, 17 have been investigated more intensively to learn the relation of quantity of chemical to fire-retarding effectiveness. Determinations have been made of the apparent moisture content of the treated wood with all chemicals, and gluing tests have been carried out on wood treated with several chemicals or combinations.

Results of Tests Not Previously Reported

Extensive Survey

The study of fire-retarding properties of chemicals has consistently followed the methods of treating and testing that were described in the 1930 and 1931

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[1] Presented at the 31st annual meeting of the American Wood-Preservers' Association held at the Pennsylvania Hotel, New York City, on January 22, 23, and 24, 1935. Published in the 1935 Proceedings of the Association.

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

[3] Published in the Proceedings of the American Wood-Preservers' Association for the years 1930, 1931, 1932, and 1933. No report was made in 1934.

reports. Because of the uniform procedure followed the results obtained and reported from time to time are considered comparable.

In the extensive or preliminary study of the effectiveness of new chemicals, standard test specimens impregnated with low absorptions and others with high absorptions are tested in the fire tube. Tables 1 and 2 contain the results of tests in the extensive survey not previously reported. Table 1 includes results of tests in which the specimens were first impregnated with chemical solutions and subsequently some of them were treated with ammonia gas; table 2 includes the results on single chemicals and combinations not involving a second treatment with ammonia gas.

Insoluble double phosphates.--In 1933, several treatments were reported in which the monobasic arsenate or phosphate of zinc or magnesium was injected into wood followed by an ammonia gas treatment of the wet or dry wood, forming theoretically an insoluble double phosphate or arsenate, as magnesium ammonium phosphate ($MgNH_4PO_4$) and zinc ammonium arsenate ($ZnNH_4AsO_4$). Various reaction products were formed in the wood at the same time, depending upon the chemicals used in the treatments. The results of these preliminary tests indicated good fire-retarding effects and the possibility of producing a non-leaching, fire-resistant treatment -- a promise, however, that subsequent tests have as yet failed to verify.

In addition to magnesium and zinc, several other divalent metals form similar compounds with phosphoric acid and ammonia. These include barium, cadmium, calcium, cobalt, manganese, and nickel.[4] Because of the similarity of compounds formed with these metals a series of treatments was made. In order to simplify comparisons the monobasic form of the phosphate of the metal was used or formed in the treating solution by combining the oxide or hydroxide of the metal with phosphoric acid. In most cases, in order to form a clear solution, it was necessary to add an excess of phosphoric acid over the theoretical quantity required to form the monobasic phosphate of the metal. This excess varied in amount; it was especially large in the case of barium, nickel, and cadmium.

Part of the specimens previously impregnated with the phosphate solution were subsequently treated with ammonia gas while wet, part were dried and then treated with ammonia gas, and a third part were tested without the gas treatment. The ammonia gas was forced into the wood under pressure and it is known that the amount used was considerably in excess of that required to complete the chemical reactions, especially when the wood was treated wet. During the subsequent drying and conditioning it is believed that most of

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[4] Except under carefully controlled conditions some tertiary nickel phosphate tends to form along with the nickel ammonium phosphate. In this report all treatments involving the nickel, ammonium, and phosphate ions are for convenience designated as nickel ammonium phosphate.

the excess ammonia volatilized though a small amount may have been adsorbed by the wood. The percentage of ammonia gas used in the treatments (column 2, table 1) was calculated on the amount theoretically required to enter into combination with the other chemicals in the wood and not on the total amount injected into the wood. The proportions of chemicals used in the treatments, the compounds theoretically formed and their proportions, the absorptions of total chemicals, and the results obtained in the fire tube tests are shown in table 1. Results of similar treatments made previously with magnesium and zinc compounds, but in which the wood was treated with ammonia gas only while wet, are shown in table 1 (runs 7A, 7B, 8A, and 8B) for comparison. All the treatments, both with and without ammonia gas, gave good fire-retarding effect, but ammonia gas treatment in most cases improved the fire-retarding effect.

Because of the difference in the atomic weights of the metals and the amount of excess phosphoric acid necessary to produce a clear treating solution, the proportion of the insoluble double phosphate and the diammonium phosphate formed in the wood with the ammonia gas treatments varied. In the heavy absorptions the percentages of the insoluble double phosphates theoretically formed in the wood were approximately as follows: Zinc ammonium phosphate 57, magnesium ammonium phosphate 51, cobalt ammonium phosphate 49, cadmium ammonium phosphate 40, calcium ammonium phosphate 40, barium ammonium phosphate 35, manganese ammonium phosphate 35, nickel ammonium phosphate 30.

Tests are now in progress to study the fire-retarding effectiveness of the insoluble double phosphates of ammonium and the metals barium calcium, magnesium, nickel, and zinc after the diammonium phosphate has been leached away. These tests are still far from complete, but preliminary results of fire tests on specimens, from which most of the soluble diammonium phosphate has been leached, indicate that the insoluble double phosphates of ammonium and the metals are not so effective as the diammonium phosphate and when present in the wood alone do not give a high degree of fire-retarding effectiveness.

Toxicity tests were made on several of the double phosphate and arsenate compounds using the wood destroying fungus Fomes annosus and a nutrient agar medium according to the standard methods employed at the Forest Products Laboratory and elsewhere. It was found that magnesium ammonium arsenate and nickel ammonium phosphate totally inhibited the growth of the organism at concentrations of 0.04 percent and 0.05 percent, respectively. The killing points were not determined, but should be very little higher. These compounds are rather unusual in that they have low solubility, but a sufficient high molecular toxicity to make the saturated solution toxic to wood destroying fungi. Zinc ammonium phosphate, zinc ammonium arsenate, and cobalt ammonium phosphate were also tested, but their saturated solutions in agar permitted growth of the fungus.

Various possibilities exist for combining the insoluble phosphates and arsenates of ammonium and the metals, such as zinc, magnesium, and nickel, to produce a treatment that has resistance to fire, decay, and insects. For example, wood treated with a solution containing the monobasic phosphates of both magnesium and nickel, followed by a treatment with ammonia gas, should resist both fire and decay. Under severe conditions of leaching its fire resistance would be reduced, but its decay resistance should be relatively permanent. Likewise, a combination of nickel ammonium phosphate or magnesium ammonium arsenate and other double phosphates of ammonium and metals constitute other possible treatments combining resistance to fire, decay, and insects. Much further work is necessary to determine the most effective and economical combinations.

Other treatments reported in table 1 involve magnesium oxide and boric acid (9A, 9B, and 9C), magnesium oxide and phosphoric and boric acids (10A, 10B, and 10C), and manganese borate (11A, 11B, and 11C) -- all with and without ammonia gas treatment. All were effective in stopping glow, but only the manganese borate treated with ammonia gas was effective in stopping flaming. The magnesium oxide-boric acid treatment was the least effective against flaming. Treating with ammonia gas increased the fire-retarding effect of all three treatments.

Insoluble phosphates from ammoniacal solutions.--Zinc ammonium phosphate, cobalt ammonium phosphate, and nickel ammonium phosphate differ from similar compounds of the other divalent metals in that they are soluble in an excess of ammonium hydroxide. This fact suggested the possibility of injecting these compounds into wood without the formation of large amounts of reaction products of high solubility, such as diammonium phosphate. Treatments No. 1 and 2 in table 2 were made using ammoniacal solutions of zinc ammonium phosphate and nickel ammonium phosphate. The drying of the wood after treatment liberated much of the excess ammonium hydroxide, leaving presumably only the double phosphate of ammonium and the respective metal in the wood. Both treatments when tested for fire-retarding properties showed low effectiveness, though the zinc ammonium phosphate did have a considerable effect in reducing the tendency to glow. This confirmed the results previously obtained when using an ammoniacal solution of zinc chloride and disodium phosphate as reported by the authors in the 1933 Proceedings of this Association. It had appeared originally that zinc ammonium phosphate formed in the wood by the action of ammonia gas on previously injected monobasic zinc phosphate had added to the fire-retarding effect of the diammonium phosphate formed at the same time.

Treatments No. 3, 4, 5, and 6 (table 2) were made in an attempt to test the effectiveness of other chemical compounds injected in ammoniacal solutions. Treatment No. 3 involving zinc borate was not effective. However, diammonium phosphate, Treatment No. 4, when injected into wood in a strongly ammoniacal solution was as effective as when injected in aqueous solution without ammonia, indicating that the effectiveness of a chemical is not necessarily reduced by injection in a strongly ammoniacal solution. Likewise, ammoniacal treatments No. 5 and 6 were effective in stopping flaming, although not in stopping glowing.

Consequently, the outcome of these tests combined with preliminary results obtained after leaching away the diammonium phosphate from wood treated with monobasic zinc phosphate indicates that neither zinc ammonium phosphate nor nickel ammonium phosphate when used alone has a high fire-retarding effectiveness.

Miscellaneous treatment.--Treatments No. 7, 8, 9, and 10 (table 2) showed good effectiveness, both in retarding flaming and in stopping glowing. The mixture of diammonium phosphate and boric acid, No. 7, combined in the proportion of 4 to 1, gave good fire resistance, as expected. This treatment should combine resistance to both fire and decay, but would not be expected to be permanent in effect under severe conditions of leaching. Another possible advantage of this mixture is a more nearly neutral reaction than would exist with either chemical alone. Treatments 8, 9, and 10 indicate that monoammonium phosphate and ammonium sulphate may be combined in rather widely different proportions and still give good fire-retarding effects.

Treatments involving manganese sulphate, ammonium carbonate, and sodium acetate, No. 11, 12, and 13 (table 2), showed these materials to be ineffective as fire retardants.

Certain chlorinated compounds are known to be noninflammable and to be used in combination with other materials to produce fire-resistant products. Three such highly chlorinated compounds were injected into wood, treatments No. 14, 15, and 16 (table 2), but had little effect on the combustion of the wood under test.

Intensive Survey

Of the several effective treatments involving the double phosphate of ammonium and divalent metals, tested in the extensive survey, magnesium ammonium phosphate was selected for more intensive study. Southern yellow pine boards were impregnated with monobasic magnesium phosphate in amounts varying from approximately 1 to 7-1/2 pounds of anhydrous chemical per cubic foot of wood and one-half of each charge was further treated with ammonia gas. The results of the tests on the treated wood -- both with and without the ammonia gas treatment -- are shown in table 3. The losses in weight when flaming stopped and the maximum temperatures, obtained in the fire tube test, are plotted against absorptions in figure 1.

The monobasic magnesium phosphate alone was appreciably less flame-retardant than diammonium phosphate and only in the heaviest absorption -- approximately 7-1/2 pounds per cubic foot or 19 pounds per 100 pounds of wood -- was a high degree of effectiveness obtained. However, when the monobasic magnesium phosphate treatment was followed by impregnation with ammonia gas, thereby forming magnesium ammonium phosphate and diammonium phosphate in the wood, the effectiveness was greatly increased -- approaching, though not exactly equaling, diammonium phosphate alone. It appears, therefore, that magnesium ammonium phosphate alone is less effective in stopping flaming than diammonium phosphate is. All absorptions of both treatments, however, were effective in stopping glowing (see table 3). Somewhat different results might have been obtained with the other double phosphates of low solubility.

Gluing Tests on Treated Wood

In the last report (1933) gluing tests were reported on wood treated with six different chemicals; ammonium chloride, ammonium sulphate, diammonium phosphate, monoammonium phosphate, zinc chloride, and a mixture of about 40 percent borax and 60 percent boric acid. Additional gluing tests have been made with the following:

Borax (67 percent) and monoammonium phosphate (33 percent).

Magnesium chloride (45 percent) and monoammonium phosphate (55 percent).

Magnesium chloride (45 percent) and monoammonium phosphate (55 percent) followed with ammonia gas.

Diammonium phosphate, and the surfaces of the treated wood sponged with a 10 percent solution of sodium hydroxide just before gluing.

The gluing tests on wood treated with diammonium phosphate were repeated in an effort to produce better joints by sponging the contact surfaces of the test pieces with caustic soda before gluing. Previous work had indicated that alkaline glues, particularly casein glues, were affected by a reaction with the chemical in the wood when the glue was applied and it was thought that a preliminary sponging of the wood surfaces with caustic soda solution might improve the results.

The methods following in preparing specimens and testing were the same as described in the earlier report. The results of joint tests in which the glued pieces were tested in shear at the glue line are shown in table 4. Values given for each glue and treatment represent the percentage of strength obtained using 100 to represent joint strengths of untreated wood, and the percentage of the joint area in which failure during test occurred in the wood.

Experience has shown that a variation of the order of plus or minus 10 percent may occur in the strength of well glued, matched, untreated wood joints. Consequently, treated wood joints showing 90 percent or more of the strength of untreated wood joints can be considered reasonably well glued. On the other hand, joints showing only 50 to 60 percent of the strength of untreated wood joints cannot be considered well glued. On this basis it must be concluded that, while most of the fire-retardant chemicals have rather seriously interfered with the making of joints with some one or more of the glues, the wood treated with the various chemicals was fairly satisfactorily glued with at least one glue.

The ammonium phosphates offered little or no interference with animal glue, somewhat more with vegetable glue, and rather seriously interfered with gluing with the low-alkaline casein glue. Even the mixtures containing an ammonium phosphate were not well glued with casein glues. Treating the surfaces of the diammonium-phosphate-treated wood with caustic soda before gluing improved the joint strengths, particularly with the low-alkaline casein glue. The chlorides of ammonium, zinc, and magnesium, likewise, interfered seriously with the making of joints with casein glues. Borax in mixture with other chemicals offered the greatest difficulty to gluing with vegetable glue. Most of the treatments affected the strength of animal glue joints even less than the vegetable glue joints.

The percentage of wood failure obtained in testing the joints is also a measure of the interference that occurred in gluing. Low wood failures, when compared with untreated wood, generally suggest interference in gluing, but, if accompanied by high strengths, the glue joints may be serviceable under dry conditions. On the other hand, low percentage of wood failures, accompanied by low strengths, are rather conclusive evidence of interference in gluing. This is especially noticeable with several of the treatments when the joints were made with casein glues. It is also noticeable in the treatments containing borax and glued with vegetable glue.

Summary of Previous Work

Tables 5 and 6 have been prepared for the purpose of summarizing the results obtained from year to year on various chemicals. Table 5 includes chemicals tested in the extensive survey in which wood in the form of test specimens is treated with two concentrations of solution, dried, and tested without machining. Table 6 includes chemicals tested in the intensive survey in which wood in the form of boards is treated with several concentrations of solution, dried, surfaced, and cut into specimens for test. In preparing table 5 only those treatments were selected in which absorptions of approximately 6 pounds of dry chemical per cubic foot of wood had shown an effectiveness equivalent to a loss in weight of about 25 percent or less or had effectively stopped glowing. Table 6 contains results on all treatments made in the intensive survey.

Only a few of the single chemicals (table 5) -- dibasic and monobasic ammonium phosphate, phosphoric acid, monobasic magnesium phosphate, boric acid, monobasic zinc phosphate, aluminum sulphate, ammonium bromide, and ammonium chloride -- stop both flaming and glowing. More intensive tests later showed boric acid and monobasic magnesium phosphate to be less effective than the extensive tests had indicated (see table 6). A large part of the most effective treatments involving a combination of chemicals (table 5) stopped both flaming and glowing.

Of the chemicals that have shown distinct fire-retarding properties the following are known to be sufficiently toxic to the wood-destroying fungus, *Fomes annosus*, to promise more or less protection of treated wood against decay:

Sodium arsenite
Nickel sulphate
Nickel phosphate, monobasic
Nickel ammonium phosphate
Sodium arsenate
Magnesium ammonium arsenate
Cupric chloride
Cobalt chloride
Cadmium chloride
Chromic chloride
Zinc chloride
Zinc phosphate, monobasic
Ammonium molybdate
Sodium molybdate
Ammonium tetraborate
Sodium tetraborate
Boric acid

Further Work

Obviously the list of chemicals so far studied could be extended to include many more chemical compounds, but the prospect of finding more effective single chemicals is not very promising. An infinite variety of formulas or combinations of the more effective chemicals is possible and much useful work could be done in developing the effectiveness and the advantages of the more promising of these mixtures. The extent and character of additional tests along these lines must yet be decided.

Table 1. Results of tests on treatments with and without ammonia gas, in extensive survey.

Treatment no.	Chemicals used in treatments[1]		Chemicals theoretically formed in wood[2]		Test results for light and heavy treatments					
					Absorption of anhydrous chemical			Results of tests in fire tube		
	Name and formula	Percentage of total anhydrous chemical	Name and formula	Percentage of total anhydrous chemical	Per cubic foot	Per 100 pounds of air dry wood	Apparent moisture content[3]	Loss in weight[4]	Maximum temperature	Tendency to glow[5]
		Percent		Percent	Pounds	Pounds	Percent	Percent	Deg. C.	
1-A	Barium hydroxide ($Ba(OH)_2$) Phosphoric acid (H_3PO_4)	21.5) 78.5)	Barium phosphate, monobasic ($Ba(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	43.6) 56.4)	1.42	4.13	7.6	66.5	720	None
1-A	Barium hydroxide ($Ba(OH)_2$) Phosphoric acid (H_3PO_4)	27.3) 72.7)	Barium phosphate, monobasic ($Ba(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	56.2) 43.8)	5.72	16.65	9.8	17.0	187	None
1-B	Barium hydroxide ($Ba(OH)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	17.2) 62.8) 20.0)	Barium ammonium phosphate ($Ba\ NH_4\ PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	26.0) 74.0)	1.79	5.27	8.0	65.2	696	None
1-B	Barium hydroxide ($Ba(OH)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	22.3) 59.4) 18.3)	Barium ammonium phosphate ($BaNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	34.1) 65.9)	7.13	20.76	7.7	16.0	191	None
1-C	Barium hydroxide ($Ba(OH)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on dry wood (NH_3)	17.2) 62.8) 20.0)	Barium ammonium phosphate ($BaNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	26.0) 74.0)	1.79	5.27	7.8	65.8	696	None
1-C	Barium hydroxide ($Ba(OH)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on dry wood (NH_3)	22.3) 59.4) 18.3)	Barium ammonium phosphate ($BaNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	34.6) 65.4)	7.13	20.76	7.9	15.8	178	None
2-A	Cadmium phosphate, monobasic ($Cd(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	66.5) 33.5)	Cadmium phosphate, monobasic ($Cd(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	66.5) 33.5)	1.08 5.66	3.10 16.55	7.5 9.6	63.2 18.5	716 193	None None
2-B	Cadmium phosphate, monobasic ($Cd(H_2PO_4)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	54.2) 27.4) 18.4)	Cadmium ammonium phosphate ($CdNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	39.9) 60.1)	1.33 6.95	3.80 20.32	6.5 6.8	64.0 16.0	728 187	None None
2-C	Cadmium phosphate, monobasic ($Cd(H_2PO_4)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on dry wood (NH_3)	54.2) 27.4) 18.4)	Cadmium ammonium phosphate ($CdNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	39.9) 60.1)	1.33 6.95	3.80 20.32	6.3 6.8	58.2 15.8	646 188	None None
3-A	Calcium hydroxide ($Ca(OH)_2$) Phosphoric acid (H_3PO_4)	21.8) 78.2)	Calcium phosphate, monobasic ($Ca(H_2PO_4)_2$ Phosphoric acid (H_3PO_4)	76.7) 23.3)	0.97 5.54	2.59 14.89	6.7 7.7	70.8 19.8	755 217	None None
3-B	Calcium hydroxide ($Ca(OH)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	17.5) 62.8) 19.7)	Calcium ammonium phosphate ($CaNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	40.2) 59.8)	1.21 6.90	3.23 18.54	6.8 7.7	67.5 16.0	742 191	None None
3-C	Calcium hydroxide ($Ca(OH)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on dry wood (NH_3)	17.5) 62.8) 19.7)	Calcium ammonium phosphate ($CaNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	40.2) 59.8)	1.21 6.90	3.23 18.54	6.8 9.0	70.0 17.2	743 198	None None
4-A	Cobalt phosphate, monobasic ($Co(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	88.2) 11.8)	Cobalt phosphate, monobasic ($Co(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	88.2) 11.8)	1.08 5.74	3.11 16.60	7.3 9.8	70.0 18.8	726 193	None None
4-B	Cobalt phosphate, monobasic ($Co(H_2PO_4)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	72.2) 9.7) 18.1)	Cobalt ammonium phosphate ($CoNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	49.2) 50.8)	1.33 7.01	3.79 20.23	7.6 8.0	70.8 17.8	715 199	None None
4-C	Cobalt phosphate, monobasic ($Co(H_2PO_4)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on dry wood (NH_3)	72.2) 9.7) 18.1)	Cobalt ammonium phosphate ($CoNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	49.2) 50.8)	1.33 7.01	3.79 20.23	7.3 8.0	68.0 16.2	713 200	None None
5-A	Manganese phosphate, monobasic ($Mn(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	91.0) 9.0)	Manganese phosphate, monobasic ($Mn(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	91.0) 9.0)	0.90	2.55	7.9	70.8	724	None
5-A	Manganese phosphate, monobasic ($Mn(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	65.2) 34.8)	Manganese phosphate, monobasic ($Mn(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	65.2) 34.8)	6.95	19.93	9.3	22.0	215	None
5-B	Manganese phosphate, monobasic ($Mn(H_2PO_4)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	75.2) 7.4) 17.4)	Manganese ammonium phosphate ($MnNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	50.4) 49.6)	1.09	3.08	7.3	67.0	702	None
5-B	Manganese phosphate, monobasic ($Mn(H_2PO_4)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	51.9) 27.7) 20.4)	Manganese ammonium phosphate ($MnNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	35.0) 65.0)	8.73	25.06	7.8	17.8	200	None

(Continued)

Table 1. Results of tests on treatments with and without ammonia gas, in extensive survey.(Continued)

Treatment no.	Chemicals used in treatments[1]: Name and formula	Chemicals used in treatments[1]: Percentage of total anhydrous chemical	Chemicals theoretically formed in wood[2]: Name and formula	Chemicals theoretically formed in wood[2]: Percentage of total anhydrous chemical	Absorption of anhydrous chemical: Per cubic foot	Absorption of anhydrous chemical: Per 100 pounds of air dry wood	Apparent moisture content[3]	Results of tests in fire tube: Loss in weight[4]	Results of tests in fire tube: Maximum temperature	Results of tests in fire tube: Tendency to glow[5]
		Percent		Percent	Pounds	Pounds	Percent	Percent	Deg. C.	
5-C	Manganese phosphate,monobasic ($Mn(H_2PO_4)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on dry wood (NH_3)	75.2) 7.4) 17.4)	Manganese ammonium phosphate ($MnNH_4PO_4$) Ammonium phosphate,dibasic ($(NH_4)_2HPO_4$)	50.7) 49.3)	1.09	3.08	7.3	68.8	732	None
5-D	Manganese phosphate,monobasic($Mn(H_2PO_4)_2$) Phosphoric acid (H_3PO_4) Ammonia gas on dry wood (NH_3)	51.9) 27.7) 20.4)	Manganese ammonium phosphate ($MnNH_4PO_4$) Ammonium phosphate,dibasic ($(NH_4)_2HPO_4$)	35.0) 65.0)	8.73	25.06	7.6	17.0	187	None
6-A	Nickel oxide (NiO) Phosphoric acid (H_3PO_4)	15.5) 84.5)	Nickel phosphate,monobasic ($Ni(H_2PO_4)_2$) Phosphoric acid (H_3PO_4)	54.4) 45.6)	1.23 5.35	3.30 14.21	7.5 8.3	67.2 19.2	742 211	None None
6-B	Nickel oxide (NiO) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	12.3) 67.3) 20.4)	Nickel ammonium phosphate[6] ($NiNH_4PO_4$) Ammonium phosphate,dibasic ($(NH_4)_2HPO_4$)	29.2) 70.8)	1.56 6.78	4.18 18.03	8.0 11.7	65.0 16.8	718 193	None None
6-C	Nickel oxide (NiO) Phosphoric acid (H_3PO_4) Ammonia gas on dry wood (NH_3)	12.3) 67.3) 20.4)	Nickel ammonium phosphate[6] ($NiNH_4PO_4$) Ammonium phosphate,dibasic ($(NH_4)_2HPO_4$)	29.2) 70.8)	1.56 6.78	4.18 18.03	7.7 9.0	67.2 16.5	728 194	None None
7-A	Magnesium oxide[7] (MgO) Phosphoric acid (H_3PO_4)	17.0) 83.0)	Magnesium phosphate,monobasic ($Mg(H_2PO_4)_2$)	100.0	1.06 5.72	3.04 16.36	7.3 9.7	67.5 14.5	721 187	None None
7-B	Magnesium oxide[7] (MgO) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	14.0) 68.2) 17.8)	Magnesium ammonium phosphate ($MgNH_4PO_4$) Ammonium phosphate,dibasic ($(NH_4)_2HPO_4$)	51.0) 49.0)	1.31 7.05	3.74 20.18	7.0 7.8	61.8 12.8	728 178	None None
8-A	Zinc oxide[7] (ZnO) Phosphoric acid (H_3PO_4)	29.3) 70.7)	Zinc phosphate,monobasic ($Zn(H_2PO_4)_2$)	100.0)	1.09 5.74	3.14 16.48	6.1 7.8	65.5 27.5	726 352	Very slight None
8-B	Zinc oxide[7] (ZnO) Phosphoric acid (H_3PO_4) Ammonia gas on wet wood (NH_3)	24.8) 59.7) 15.5)	Zinc ammonium phosphate ($ZnNH_4PO_4$) Ammonium phosphate,dibasic($(NH_4)_2HPO_4$)	57.4) 42.6)	1.30 6.82	3.76 19.72	6.9 7.1	60.5 14.5	721 192	None None
9-A	Magnesium oxide (MgO) Boric acid (H_3BO_3)	6.6) 93.4)	Magnesium borate (MgB_6O_{10}) Boric acid (H_3BO_3)	55.6) 44.4)	0.78 4.17	2.21 11.55	8.5 11.8	72.5 61.8	757 649	Very slight None
9-B	Magnesium oxide (MgO) Boric acid (H_3BO_3) Ammonia gas on wet wood (NH_3)	5.8) 82.9) 11.3)	Magnesium hydroxide ($Mg(OH)_2$) Ammonium tetraborate($(NH_4)_2B_4O_7$)	11.7) 88.3)	0.86 4.62	2.44 12.82	8.0 11.4	69.5 43.2	754 305	None None
9-C	Magnesium oxide (MgO) Boric acid (H_3BO_3) Ammonia gas on dry wood (NH_3)	5.8) 82.9) 11.3)	Magnesium hydroxide ($Mg(OH)_2$) Ammonium tetraborate ($(NH_4)_2B_4O_7$)	11.7) 88.3)	0.86 4.62	2.44 12.82	8.7 11.2	72.5 53.2	735 383	None None
10-A	Magnesium oxide (MgO) Phosphoric acid (H_3PO_4) Boric acid (H_3BO_3)	13.9) 67.1) 19.0)	Magnesium phosphate,monobasic ($Mg(H_2PO_4)_2$ Boric acid (H_3BO_3)	79.7) 20.3)	1.03 5.22	2.64 13.40	7.7 8.2	72.5 59.0	752 666	None None
10-B	Magnesium oxide (MgO) Phosphoric acid (H_3PO_4) Boric acid (H_3BO_3) Ammonia gas on wet wood (NH_3)	11.5) 56.1) 15.7) 16.7)	Magnesium ammonium phosphate ($MgNH_4PO_4$) Ammonium tetraborate ($(NH_4)_2B_4O_7$) Ammonium phosphate,dibasic ($(NH_4)_2HPO_4$)	44.1) 13.5) 42.4)	1.19 6.00	3.09 15.41	8.8 11.3	59.2 28.2	607 294	None None
10-C	Magnesium oxide (MgO) Phosphoric acid (H_3PO_4) Boric acid (H_3BO_3) Ammonia gas on dry wood (NH_3)	11.5) 56.1) 15.7) 16.7)	Magnesium ammonium phosphate ($MgNH_4PO_4$) Ammonium tetraborate($(NH_4)_2B_4O_7$) Ammonium phosphate,dibasic ($(NH_4)_2HPO_4$)	44.1) 13.5) 42.4)	1.19 6.00	3.09 15.41	7.7 8.8	71.5 24.8	749 363	None None
11-A	Manganese borate (MnB_4O_7)	100.0	Manganese borate ($MnB407$)	100.0	1.12 5.64	3.06 16.06	7.8 8.0	74.5 59.5	737 600	None None
11-B	Manganese borate (MnB_4O_7) Ammonia gas on wet wood (NH_3)	74.9) 25.1)	Basic manganese borate[8]	100.0	1.12 5.64	3.06 16.06	8.5 9.0	69.0 19.0	718 204	None None
11-C	Manganese borate (MnB_4O_7) Ammonia gas on dry wood (NH_3)	74.9) 25.1)	Basic manganese borate[8]	100.0	1.12 5.64	3.06 16.06	8.0 8.5	73.2 20.5	731 217	None None

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[1] Percentages of ammonia gas used in treatments calculated from the amount theoretically required to enter into combination with other chemicals in the wood.

[2] It is assumed that there was no selective absorption of chemicals by the wood and that they were present in the same proportions as in the solutions.

[3] Determined by weighing the seasoned treated wood before and after drying for 24 hours at 215° F. to 220° F.; all specimens being brought to equilibrium with air at 30 percent relative humidity and 80° F. before determining apparent moisture content and before testing.

[4] When flaming stopped

[5] Based on untreated wood as moderate

[6] Possible formation of any tertiary nickel phosphate disregarded in calculations.

[7] These results, reported in 1933, included in the present report for comparison.

[8] Exact chemical compounds formed unknown.

Table 2. Results of tests on miscellaneous treatments in extensive survey.

Treatment no.	Chemicals used in treatments[1]		Chemicals theoretically formed in wood[2]		Test results for light and heavy absorptions					
	Name and formula	Percentage of total anhydrous chemical	Name and formula	Percentage of total anhydrous chemical	Absorption of anhydrous chemical		Apparent moisture content[3]	Results of tests in fire tube		
					Per cubic foot	Per 100 pounds of air-dry wood		Loss in weight[4]	Maximum temperature	Tendency to glow[5]
		Percent		Percent	Pounds	Pounds	Percent	Percent	Deg. C.	
1	Zinc oxide (ZnO) Ammonium phosphate, monobasic ($NH_4H_2PO_4$) Ammonium hydroxide (NH_4OH)	41.4) 58.6)	Zinc ammonium phosphate ($ZnNH_4PO_4$)	100.0	1.00 4.97	2.55 12.55	6.9 7.1	77.5 69.5	757 755	None Very slight
2	Nickel phosphate ($Ni_3(PO_4)_2$) Ammonium hydroxide (NH_4OH)	84.0) 16.0)	Nickel ammonium phosphate[6] ($NiNH_4PO_4$) Nickel hydroxide ($Ni(OH)_2$)	78.8) 21.2)	0.90 3.17	2.29 10.81	9.0 11.5	75.8 70.5	748 729	Moderate Moderate
3	Zinc borate ($ZnBO_3$) Ammonium hydroxide (NH_4OH)	100.0	Basic zinc borate[7]	100.0	1.18 4.26	3.03 10.96	8.3 9.0	69.0 59.5	750 702	Slight None
4	Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$) Ammonium hydroxide (NH_4OH)	100.0	Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$)	100.0	1.03 5.47	2.90 15.58	6.8 7.3	67.0 16.5	731 178	None None
5	Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$) Molybdic acid (H_2MoO_4) Ammonium hydroxide (NH_4OH)	5.4) 79.8) 14.8)	Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$) Ammonium molybdate ($(NH_4)_6Mo_7O_{24}$)	5.6) 94.4)	1.03 5.68	3.06 16.18	7.6 8.4	69.8 22.0	760 218	Moderate Moderate
6	Zinc ammonium phosphate ($ZnNH_4PO_4$) Ammonium phospho-molybdate ($(NH_4)_3PO_4.12MoO_3$) Ammonium hydroxide (NH_4OH)	48.7) 43.7) 7.6)	Zinc ammonium phosphate ($ZnNH_4PO_4$) Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$) Ammonium molybdate ($(NH_4)_6Mo_7O_{24}$)	49.2) 3.1) 47.7)	1.04 5.51	2.95 15.55	7.0 6.7	71.0 24.8	753 250	Slight Slight
7	Ammonium phosphate dibasic ($(NH_4)_2HPO_4$) Boric acid (H_3BO_3)	80.0) 20.0)	Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$) Boric acid (H_3BO_3)	80.0) 20.0)	1.00 5.38	2.77 14.93	7.2 8.0	66.2 16.2	742 205	None None
8	Ammonium phosphate, monobasic ($NH_4H_2PO_4$) Ammonium sulphate ($(NH_4)_2SO_4$)	36.0) 64.0)	Ammonium phosphate, dibasic ($(NH_4)_2HPO_4$) Ammonium sulphate ($(NH_4)_2SO_4$)	36.0) 64.0)	0.97 5.27	2.73 14.98	7.0 7.0	67.8 15.0	760 192	None None
9	Same as 8 but different proportions	49.0) 51.0)	Same as 8 but different proportions	49.0) 51.0)	1.12 5.54	3.19 15.38	7.0 6.7	66.0 14.8	727 195	None None
10	Same as 8 but different proportions	63.0) 37.0)	Same as 8 but different proportions	63.0) 37.0)	1.08 5.43	2.81 15.01	7.0 6.8	67.8 14.0	733 192	None None
11	Manganese sulphate ($MnSO_4$)	100.0	Manganese sulphate (M_nSO_4)	100.0	1.07 5.46	2.68 14.04	8.3 10.0	78.5 68.3	757 754	Moderate Moderate
12	Ammonium carbonate ($(NH_4)_2CO_3$)	100.0	Ammonium carbonate ($(NH_4)_2CO_3$)	100.0	1.05 5.34	2.94 14.64	7.0 7.3	79.2 77.5	802 743	Slight Very slight
13	Sodium acetate ($NaC_2H_3O_2$)	100.0	Sodium acetate ($NaC_2H_3O_2$)	100.0	1.33 5.62	3.90 16.32	7.7 8.8	68.2 66.0	777 799	Moderate Slight
14	Hexachlorbenzene (C_6Cl_6) (dissolved in orthodichlorbenzene)	100.0	Hexachlorbenzene (C_6Cl_6)	100.0	0.91 3.58	2.59 9.66	8.2 10.6	81.5 83.8	796 742	Moderate Moderate
15	Orthochlordiphenylether ($C_{12}H_9ClO$) (dissolved in carbon tetrachloride)	100.0	Orthochlordiphenylether ($C_{12}H_9ClO$)	100.0	1.04 6.05	2.94 16.50	6.7 6.5	81.2 82.2	771 729	Moderate Moderate
16	Hexachlordiphenyl ($C_{12}H_4Cl_6$) (dissolved in carbon tetrachloride)	100.0	Hexachlordiphenyl ($C_{12}H_4Cl_6$)	100.0	1.35 6.82	3.76 19.00	7.0 6.7	81.5 80.8	817 682	Moderate Moderate

[1] Percentages of ammonium hydroxide used in treatments given only where it is considered to have entered into combination with other chemicals.

[2] It is assumed that there was no selective absorption of chemicals by the wood and that they were present in the same proportions as in the treating solutions.

[3] Determined by weighing the seasoned, treated wood before and after drying for 24 hours at 215° to 220°F.; all specimens being brought to equilibrium with air at 30 percent relative humidity and 80°F. before determining apparent moisture content and before testing.

[4] When flaming stopped.

[5] Based on untreated wood as moderate.

[6] Possible formation of any tertiary nickel phosphate disregarded in calculations.

[7] Exact chemical compounds formed unknown.

Table 3.--Results of tests on phosphates of magnesium in intensive survey.

Absorption of total anhydrous chemical[1]		Apparent moisture content[2]	Loss in weight[3]	Results of tests			
Per cubic foot	Per 100 pounds of air-dry wood			Rate of loss in weight[4]	Maximum temperature	Rate of temperature increase[5]	Tendency to glow
Pounds	Pounds	Percent	Percent	Percent per min.	Degrees C.	Degrees C. per min.	
Monobasic magnesium phosphate -- $Mg(H_2PO_4)_2$							
1.06	2.96	7.4	75.7	15.87	744	252	None
2.18	6.17	7.5	70.0	15.15	717	218	None
3.10	8.59	7.1	67.4	14.18	713	225	None
5.45	14.94	8.9	54.5	10.40	579	151	None
7.44	19.20	10.5	18.4	4.61	196	79	None
Monobasic magnesium phosphate followed by treatment with ammonia gas[6]							
1.31	3.62	8.1	70.0	14.80	715	218	None
2.68	7.74	10.4	49.8	10.05	488	118	None
3.85	10.76	11.0	21.6	5.40	204	76	None
6.66	18.98	13.1	16.1	4.03	176	62	None
9.60	24.06	13.2	14.0	3.50	171	57	None

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[1] Calculated on basis of air-dry wood.

[2] Determined by weighing the seasoned, treated wood before and after drying for 24 hours at 215 to 220 degrees F.; all specimens being brought to equilibrium with air at 30 percent relative humidity and 80 degrees F., before determining apparent moisture content and before testing.

[3] When the flaming stopped.

[4] Calculated by dividing the loss in weight when flaming stopped by the time of flaming.

[2] Calculated by dividing the maximum temperature by the length of time of its occurrence.

[6] Gas treatment applied while wood was wet from treatment, presumably producing about 51 percent magnesium ammonium phosphate and 49 percent diammonium phosphate by weight.

Table 4.--Results of gluing tests on wood treated with fire retardant chemicals

Chemicals	Absorption per cubic foot of wood	Animal glue		High-alkaline casein glue		Low-alkaline casein glue		Vegetable glue	
		Percentage of strength of untreated wood	Wood failure	Percentage of strength of untreated wood	Wood failure	Percentage of strength of untreated wood	Wood failure	Percentage of strength of untreated wood	Wood failure
	Pounds	Percent							
Diammonium phosphate.........	3.44	96	47	76	28	60	8	84	45
Monoammonium phosphate.....	4.21	96	67	84	24	65	3	85	29
Ammonium sulphate.........	5.66	89	59	84	21	73	7	82	49
Ammonium chloride......	5.10	77	36	64	4	47	3	95	80
Zinc chloride...	5.31	86	62	68	3	56	1	87	52
Borax 39% and boric acid 61%	5.31	84	78	75	40	86	18	66	23
Borax 67% and monoammonium phosphate 33%.	4.63	89	66	66	14	71	6	53	1
Magnesium chloride 45% monoammonium phosphate 55%.....	5.23	81	69	66	21	53	2	76	40
Magnesium chloride 45% monoammonium phosphate 55% and ammonia gas...	5.19	107	51	68	3	65	4	94	61
Diammonium phosphate (surfaces sponged with caustic soda).	3.44	94	54	84	8	107	44	94	42
Untreated wood..	.00	100	85	100	61	100	42	100	64

Table 5.--Summary of effective fire-retarding chemicals tested in extensive survey (p. 1 of table 5)

Chemicals used in treatment[1]		Absorption of anhydrous chemical per cubic foot	Loss in[2] weight in fire tube	Tendency[3] to glow	Apparent[4] moisture content	Date originally published
Name	Percentage of total anhydrous chemical					
		Pounds	Percent		Percent	
Aluminum chloride	100	1.16	72.0	Moderate	12.2	1931
		6.12	15.7	Moderate	28.1	
Aluminum sulphate	100	1.30	72.5	Slight	9.2	1932
		6.38	19.8	None	14.7	
Ammonium arsenite	100	.79	78.2	Moderate	8.8	1932
		5.13	23.5	Moderate	7.9	
Ammonium bromide	100	1.14	61.0	Moderate	8.0	1931
		4.44	18.5	None	9.6	
Ammonium chloride[5]	100	1.26	30.8	Moderate	8.0	1931
		5.36	18.8	None	7.6	
Ammonium phosphate dibasic[5]	100	1.16	57.8	None	8.5	1931
		5.86	15.0	None	9.2	
Ammonium phosphate, monobasic[5]	100	1.16	59.8	None	6.8	1931
		5.14	17.8	None	7.1	
Ammonium sulphate[5]	100	1.38	72.5	Moderate	8.3	1931
		5.64	20.2	Moderate	8.6	
Barium hydroxide	100	1.00	72.0	Moderate	7.6	1931
		6.13	24.2	Slight	9.5	
Boric acid[5]	100	1.16	71.5	None	9.7	1931
		4.45	21.2	None	13.2	
Calcium arsenate, monobasic	100	1.05	74.8	Moderate	7.3	1933
		5.68	20.0	Moderate	8.1	
Calcium chloride	100	1.23	71.0	Moderate	9.4	1931
		6.12	17.2	Slight	18.1	
Chromic chloride	100	1.13	71.0	Heavy	9.5	1931
		5.75	17.3	Heavy	14.0	
Cobaltous chloride	100	.85	75.0	Heavy	7.8	1932
		4.21	19.2	Slight	10.9	
Cupric chloride	100	1.26	76.0	Heavy	9.3	1932
		6.60	24.0	Moderate	17.4	
Lithium chloride	100	1.11	44.8	Slight	7.6	1932
		4.56	18.8	Slight	13.8	
Magnesium chloride	100	1.12	48.0	Moderate	12.0	1931
		6.32	15.0	Slight	18.3	

(continued)

Table 5.--Summary of effective fire-retarding chemicals tested in extensive survey (continued) (p. 2 of table 5)

Chemicals used in treatment[1]		Absorption of anhydrous chemical per cubic foot	Loss in[2] weight in fire tube	Tendency[3] to glow	Apparent[4] moisture content	Date originally published
Name	Percentage of total anhydrous chemical					
		Pounds	Percent		Percent	
Magnesium phosphate, monobasic[5]	100	0.94	69.6	None	7.3	1933
		5.02	20.2	None	9.7	
Manganese borate	100	1.06	71.8	Moderate	8.6	1932
		5.86	26.8	Slight	10.7	
Manganese chloride	100	1.07	71.5	Heavy	9.8	1931
		5.90	17.5	Moderate	21.9	
Nickel sulphate	100	1.15	74.8	Moderate	8.6	1931
		6.16	25.0	Slight	14.5	
Phosphoric acid	100	1.46	53.0	None	7.5	1932
		5.89	18.0	None	11.4	
Sodium arsenate	100	1.13	35.0	Moderate	8.1	1931
		6.00	14.8	Moderate	10.9	
Sodium arsenite	100	1.02	29.5	Slight	7.1	1931
		5.86	16.2	Slight	9.6	
Sodium tetraborate (borax)[5]	100	1.42	34.5	Moderate	10.2	1931
		6.17	11.8	Moderate	19.5	
Sodium molybdate	100	1.24	49.2	Heavy	7.9	1932
		6.30	21.2	Moderate	8.5	
Sodium selenite	100	1.16	61.0	Moderate	6.6	1932
		6.26	23.5	Moderate	10.1	
Stannic ammonium chloride	100	1.22	73.8	Moderate	8.4	1932
		6.32	19.2	Slight	8.8	
Stannic chloride	100	1.34	68.5	Slight	8.7	1932
		6.48	17.0	Slight	15.0	
Stannous chloride	100	.99	71.5	Slight	8.7	1932
		5.52	20.0	Slight	10.4	
Zinc chloride[5]	100	1.07	63.2	Moderate	7.9	1931
		5.97	17.2	Slight	11.2	
Zinc phosphate, monobasic	100	1.09	65.5	V. slight	6.1	1933
		5.74	27.5	None	7.8	
Barium hydroxide	56)	1.42	66.5	None	7.6	Present report
Phosphoric acid	44)	5.72	17.0	None	9.8	
Barium hydroxide	45)	1.79	65.5	None	7.9	"
Phosphoric acid	35)	7.13	15.9	None	7.8	
Ammonia gas	20)					

(continued)

Table 5.--Summary of effective fire-retarding chemicals tested in extensive survey (continued) (p. 3 of table 5)

Chemicals used in treatment[1]		Absorption of anhydrous chemical per cubic foot	Loss in[2] weight in fire tube	Tendency[3] to glow	Apparent[4] moisture content	Date originally published
Name	Percentage of total anhydrous chemical					
		Pounds	Percent		Percent	
Cadmium phosphate, monobasic	66.5)	1.08	63.2	None	7.5	Present report
Phosphoric acid	33.5)	5.66	18.5	None	9.6	
Cadmium phosphate, monobasic	54.2)	1.33	61.1	None	6.4	"
Phosphoric acid	27.4)	6.95	15.9	None	6.8	
Ammonia gas	18.4)					
Calcium hydroxide	21.8)	.97	70.8	None	6.7	"
Phosphoric acid	78.2)	5.54	19.8	None	7.7	
Calcium hydroxide	17.5)	1.21	68.8	None	6.8	"
Phosphoric acid	62.8)	6.90	16.6	None	8.4	
Ammonia gas	19.7)					
Cobalt phosphate, monobasic	88.2)	1.08	70.0	None	7.3	"
Phosphoric acid	11.8)	5.74	18.8	None	9.8	
Cobalt phosphate, monobasic	72.2)	1.33	69.4	None	7.5	"
Phosphoric acid	9.7)	7.01	17.0	None	8.0	
Ammonia gas	18.1)					
Magnesium chloride[5]	45.2)	1.58	72.2	None	10.2	1933
Ammonium phosphate, monbasic	) 54.8)	8.42	15.8	None	17.0	
Magnesium chloride[5]	38.9)	1.83	44.3	V. slight	8.3	1933
Ammonium phosphate, monobasic	) 47.2)	9.79	15.0	None	10.6	
Ammonia gas	13.9)					
Magnesium chloride[5]	38.2)	1.62	64.5	Slight	7.0	1933
Sodium phosphate, monobasic	) 48.2)	11.43	15.4	V. slight	6.9	
Ammonia gas	13.6)					

(continued)

Table 5.--Summary of effective fire-retarding chemicals tested in extensive survey (continued) (p. 4 of table 5)

Chemicals used in treatment[1]		Absorption of anhydrous chemical per cubic foot	Loss in[2] weight in fire tube	Tendency[3] to glow	Apparent[4] moisture content	Date originally published
Name	Percentage of total anhydrous chemical					
		Pounds	Percent		Percent	
Magnesium phosphate, dibasic	55.1)	0.81	72.0	None	7.8	1933
Phosphoric acid	44.9)	4.32	25.8	V. slight	9.5	
Magnesium phosphate, dibasic	44.7)	1.00	66.6	None	7.9	1933
Phosphoric acid	36.4)	5.32	18.0	None	7.7	
Ammonia gas	18.9)					
Magnesium oxide[5]	14.0)	1.31	61.8	None	7.0	1933
Phosphoric acid	68.2)	7.05	12.8	None	7.8	
Ammonia gas	17.8)					
Manganese borate	74.9)	1.49	71.7	None	8.3	Present report
Ammonia gas	25.1)	7.53	19.8	None	8.8	
Manganese phosphate, monobasic	65.2)	.90	70.8	None	7.9	"
Phosphoric acid	34.8)	6.95	22.0	None	9.3	
Manganese phosphate, monobasic	51.9)	1.09	67.9	None	7.3	"
Phosphoric acid	27.7)	8.73	17.4	None	7.7	
Ammonia gas	20.4)					
Nickel oxide	27.9)	1.23	67.2	None	7.5	"
Phosphoric acid	72.1)	5.35	19.2	None	8.3	
Nickel oxide	22.0)	1.56	66.1	None	7.9	"
Phosphoric acid	56.9)	6.78	16.7	None	10.4	
Ammonia gas	21.1)					
Zinc chloride	52.0)	1.17	67.0	Slight	7.4	1933
Boric acid	48.0)	6.31	17.8	None	8.0	
Zinc chloride[5]	54.2)	1.45	72.5	V. slight	7.6	1933
Ammonium phosphate, monobasic	45.8)	7.83	17.5	V. slight	10.2	

(continued)

Table 5.--Summary of effective fire-retarding chemicals tested in extensive survey (continued) (p. 5 of table 5)

Chemicals used in treatment[1]		Absorption of anhydrous chemical per cubic foot	Loss in[2] weight in fire tube	Tendency[3] to glow	Apparent[4] moisture content	Date originally published
Name	Percentage of total anhydrous chemical					
		Pounds	Percent		Percent	
Zinc chloride[5]	47.8)	1.65	68.7	Slight	7.4	1933
Ammonium phosphate, monobasic	40.3)	8.89	13.7	V. slight	6.6	
Ammonia gas	11.9)					
Zinc oxide	24.8)	1.30	60.2	None	6.9	1933
Phosphoric acid	59.7)	6.82	14.5	None	7.1	
Ammonia gas	15.5)					
Molybdic acid	79.8)	1.03	69.8	Moderate	7.6	Present report
Ammonium phosphate, dibasic	5.4)	5.68	22.0	Moderate	8.4	
Ammonium hydroxide	14.8)					
Zinc ammonium phosphate	48.7)	1.04	71.0	Slight	7.0	"
Ammonium phospho molybdate	43.7)	5.51	24.8	Slight	6.7	
Ammonium hydroxide	7.6)					
Magnesium chloride	25.4)	2.96	62.8	V. slight	10.6	1933
Phosphoric acid	38.3)	15.43	13.5	None	9.6	
Sodium ammonium phosphate (Microcosmic salt)	36.3)					
Magnesium chloride	21.3)	3.49	21.2	V. slight	7.9	1933
Phosphoric acid	32.5)	18.18	10.5	None	7.0	
Sodium ammonium phosphate (Microcosmic salt)	30.6)					
Ammonia gas	15.6)					
Magnesium chloride	38.2)	2.05	46.7	V. slight	8.6	1933
Sodium phosphate, dibasic	28.4)	11.05	14.1	None	7.6	
Phosphoric acid	19.8)					
Ammonia gas	13.6)					
Zinc chloride	47.0)	1.91	63.9	Slight	7.1	1933
Sodium phosphate, monobasic	41.3)	10.32	15.9	V. slight	7.3	
Ammonia gas	11.7)					

(continued)

Table 5.--Summary of effective fire-retarding chemicals tested in extensive survey (continued) (p. 6 of table 5)

Chemicals used in treatment[1]		Absorption of anhydrous chemical per cubic foot	Loss in[2] weight in fire tube	Tendency[3] to glow	Apparent[4] moisture content	Date originally published
Name	Percentage of total anhydrous chemical					
		Pounds	Percent		Percent	
Magnesium chloride........	28.9)	2.40	43.5	Moderate	8.2	1933
Arsenic acid..............	29.1)	15.45	12.0	Slight	11.0	
Sodium arsenate, tribasic.	42.0)					
Magnesium chloride........	26.1)	2.65	22.4	Moderate	7.8	1933
Arsenic acid..............	26.3)	17.42	9.7	None	10.2	
Sodium arsenate, tribasic.	38.2)					
Ammonia gas...............	9.4)					

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[1] Results of treatments involving ammonia gas on wet and dry wood averaged.

[2] When flaming stopped.

[3] Based on untreated wood as "moderate."

[4] Determined by weighing the seasoned treated wood before and after drying for 24 hours at 215° to 220° F.; all specimens having been brought to equilibrium with air at 30 percent relative humidity and 80° F., before determining apparent moisture content and before testing.

[5] Tested also in intensive survey.

(Table 5 concluded)

Table 6.--Summary of treatments made in intensive survey (p. 1 of table 6)

Chemicals	Percentage of total anhydrous chemical used	Absorption of anhydrous chemical per cubic foot of wood	Loss[1] in weight	Tendency[2] to glow	Apparent[3] moisture content	Date originally published
		Pounds	Percent		Percent	
None (untreated wood)			83.5	Moderate	6.2	1931
Ammonium chloride	100	1.50	66.5	Slight	6.0	1931
		2.10	53.8	Slight	7.0	
		3.14	23.3	Slight	7.0	
		5.36	24.2	Slight	6.4	
		7.54	19.7	V. slight	6.9	
Ammonium phosphate (dibasic)	100	.90	69.4	None	6.6	1931
		1.84	43.4	None	7.5	
		3.23	21.8	None	6.9	
		5.15	17.9	None	7.6	
		7.25	17.1	None	6.9	
Ammonium phosphate (monobasic)	100	.91	67.4	None	6.4	1931
		1.84	56.9	None	7.4	
		2.60	26.5	None	6.9	
		4.99	19.0	None	6.2	
		7.29	15.7	None	7.7	
Ammonium sulphate	100	1.35	70.4	Slight	6.6	1931
		1.86	64.3	Slight	7.2	
		3.17	31.6	Slight	7.4	
		4.96	25.9	Slight	6.6	
		6.70	20.1	Slight	6.2	
Sodium tetraborate (borax)	100	1.02	54.4	Moderate	7.6	1931
		1.76	36.0	Moderate	7.7	
		3.08	25.0	Moderate	7.8	
		5.36	21.8	Moderate	10.2	
		6.02	20.0	Moderate	10.6	
Boric acid	(60	1.18	69.5	Slight	8.4	1932
Sodium tetraborate (borax)	(40	2.08	64.6	Slight	8.7	
		3.11	60.3	Slight	10.5	
		5.32	28.3	Slight	9.2	
		7.14	19.1	None	9.3	

(continued)

Table 6.--Summary of treatments made in intensive survey (continued) (p. 2 of table 6)

Chemicals	Percentage of total anhydrous chemical used	Absorption of anhydrous chemical per cubic foot of wood	Loss[1] in weight	Tendency[2] to glow	Apparent[3] moisture content	Date originally published
		Pounds	Percent		Percent	
		1.09	68.6	V. slight	6.5	
		2.20	52.9	V. slight	7.6	
Borax	(67	3.41	27.2	None	9.0	1933
Ammonium phosphate	(33	5.69	16.5	None	7.7	
(monobasic)		8.49	14.6	None	7.7	
		1.00	78.2	None	8.4	
		2.04	75.1	None	8.8	
		3.32	72.2	None	10.2	
Boric acid	100	5.42	66.8	None	11.2	1932
		6.83	58.4	None	11.8	
		8.74	29.9	None	12.2	
		1.09	77.1	None	8.0	
		2.19	72.0	None	8.4	
Magnesium chloride	(45	3.19	67.8	None	....	1933
Ammonium phosphate	(55	5.85	21.1	None	14.5	
(monobasic)		8.39	17.4	None	14.7	
		1.24	71.4	V. slight	8.2	
Magnesium chloride	(39	2.61	52.5	None	9.4	
Ammonium phosphate	(47	3.88	22.5	None	10.4	1933
(monobasic)	(	6.63	16.6	None	11.1	
Ammonia gas	(14	9.66	15.6	None	11.9	
		1.14	76.9	Moderate	6.8	
Magnesium chloride	(44	2.34	73.3	Moderate	7.6	
Sodium phosphate	(56	3.57	70.2	Slight	8.3	1933
(monobasic)		5.78	54.2	V. slight	....	
		8.83	33.2	V. slight	12.5	
		1.32	66.4	Slight	7.3	
Magnesium chloride	(38	2.64	54.9	None	8.6	
Sodium phosphate	(48	4.01	27.4	None	9.8	1933
(monobasic)	(	6.85	19.4	None	11.7	
Ammonia gas	(14	10.09	16.2	None	11.9	

(continued)

Table 6.--Summary of treatments made in intensive survey (continued) (p. 3 of table 6)

Chemicals	Percentage of total anhydrous chemical used	Absorption of anhydrous chemical per cubic foot of wood	Loss in weight[1]	Tendency to glow[2]	Apparent moisture content[3]	Date originally published
		Pounds	Percent		Percent	
Magnesium phosphate (monobasic)	100	1.06	75.7	None	7.4	Present report
		2.18	70.0	None	7.5	
		3.10	67.4	None	7.1	
		5.45	54.5	None	8.9	
		7.44	18.4	None	10.5	
Magnesium phosphate (monobasic) Ammonia gas	81 19	1.31	70.0	None	8.1	Present report
		2.68	49.8	None	10.4	
		3.85	21.6	None	11.0	
		6.66	16.1	None	13.1	
		9.38	14.0	None	13.2	
Zinc chloride	100	1.13	73.8	Moderate	7.0	1931
		1.88	63.5	Moderate	7.4	
		2.77	47.7	Moderate	7.0	
		5.08	20.7	Moderate	8.2	
		8.28	18.3	Moderate	9.6	
Zinc chloride Ammonium phosphate (monobasic)	54 46	1.04	75.8	None	7.1	1933
		2.09	69.8	None	7.0	
		3.24	65.8	None	5.8	
		5.40	22.9	None	6.6	
		7.60	18.4	None	7.5	
Zinc chloride Ammonium phosphate (monobasic) Ammonia gas	48 40 12	1.19	72.6	None	7.0	1933
		2.27	67.9	None	6.4	
		3.74	37.8	None	5.7	
		6.15	18.1	None	6.0	
		8.55	16.3	None	5.9	

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[1] When flaming stopped.

[2] Based on untreated wood as "moderate."

[3] Determined by weighing the seasoned treated wood before and after drying for 24 hours at 215° to 220°F.; all specimens having been brought to equilibrium with air at 30 percent relative humidity and 80° F., before determining apparent moisture content and before testing.

(Table 6 concluded)

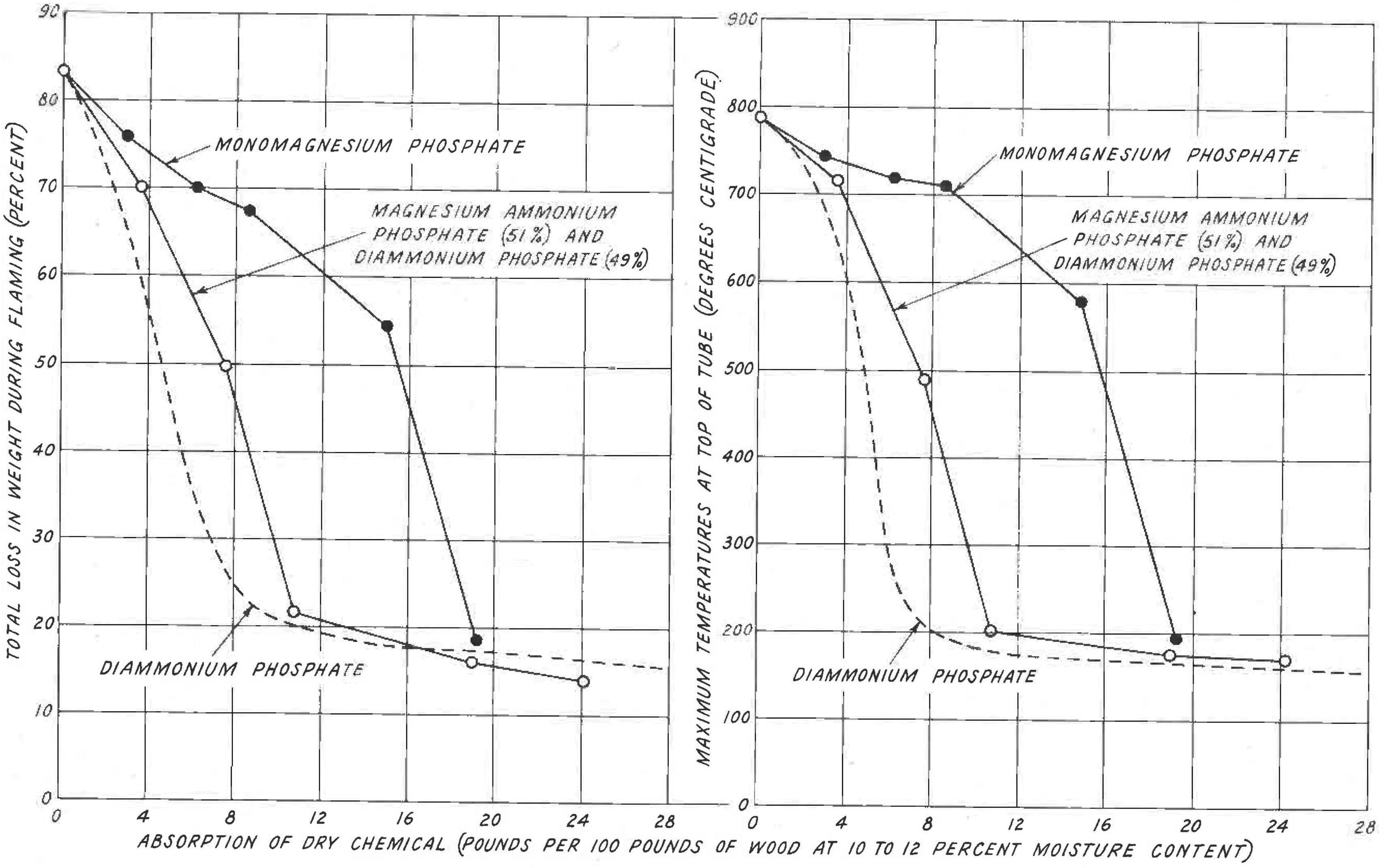

FIG. 1
FIRE RESISTANCE OF PHOSPHATES OF MAGNESIUM
COMPARED WITH DIAMMONIUM PHOSPHATE

Z M 24783 F