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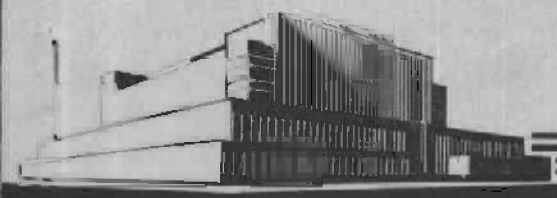

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

THE EFFECT OF FIRE-RETARDANT CHEMICALS ON GLUES USED IN PLYWOOD MANUFACTURE[1]

By

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Introduction

The growing use of plywood for structural purposes has evoked considerable interest in the possibility of reducing fire hazard by use of veneer treated with fire-retarding chemicals. Plywood is extensively used in interior and exterior constructions (4),[3] and a method of successfully fireproofing and bonding treated veneer should greatly increase its field of application. A method of improving plywood's fire resistance has become especially important where protection from incendiary bombs is wanted.

There are three methods by which fire-retardant plywood can be made:

1. Coating the plywood with fire-retardant paint.
2. Impregnating the plywood with fire-retardant chemicals.
3. Impregnating the veneer with fire-retardant chemicals before gluing.

The first method would be the simplest; however, a paint that is as effective as impregnation with chemicals has not yet been made. The disadvantage of the second alternative is that a good water-resistant glue must be used to withstand the impregnation treatment. The impregnation of the veneer with fireproofing chemicals would be a very satisfactory and simple method if a successful glue bond could be obtained. This procedure raises a very definite problem, that of the effect of fire-retardant chemicals on the uncured glue.

Previous experimental work by Brouse (1) on gluing of veneer treated with monoammonium phosphate gave the following results:

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[1]The material here presented was originally submitted in 1942 by the author as a thesis for the degree of Bachelor of Science in chemistry at the University of Wisconsin.

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

[3]Numbers in parentheses refer to literature cited at the end of this report.

Glue Used		Results
1. Hot press blood	-	Successful
2. Phenolic resin, film form	-	Successful
3. Soybean	-	Unsuccessful
4. Phenolic resin, liquid form	-	Unsuccessful
5. Starch	-	Unsuccessful
6. Casein	-	Unsuccessful

Some of the synthetic-resin glues appear to possess more resistance to fire than other commonly used glues, such as blood, casein, starch, and soybean glues. It was thought that, due to the chemical composition of these resin glues, fire-retardant chemicals might have less effect on them. The gluing tests (1) made in 1934 with synthetic-resin glues, on veneer treated with various fire-retardant chemicals, gave varied and nonconclusive results.

This thesis covers a more extensive study by the writer of the effects of fire-retardant chemicals on the two most widely used types of resin glues, urea-formaldehyde resins and phenol-formaldehyde resins. The latter are the more resistant to fire.

The chemistry of the urea-formaldehyde reaction is explicitly recorded by Ellis (2). A hypothesis concerning the mechanism of formation of urea-formaldehyde resins has been advanced by Redfern (2), who attributes the resin formation to the polymerization of dimethyleneurea.

Dimethylol urea is first formed by the action of formaldehyde on urea. Since, however, the condensation is carried out in acid solution, pH 4 to 7, it is conceivable that two molecules of water may be eliminated to yield dimethyleneurea.

Further heating then results in polymerization, which is represented as a saturated chain. The final stage of polymerization, or hardening of the resin, converts the chain formation into a ring structure which satisfies the unsaturated free end valences. This final hardening of cold-setting urea-formaldehyde resins is accelerated by treating the uncured condensation products with weak acid solutions of pH 4 to 7. The final pH of the cured resin may be much lower if the acid accelerator is not buffered. The Canadian specifications on pH of cured resin limit the acidity to a minimum pH of 3 and the U. S. Army-Navy Aeronautical Specification AN-G-8 limits it to not less than 2.5. Too much acidity, of course, would be harmful to the wood.

Hot-press urea resins (2) are incorporated with curing catalysts which shorten the duration of the actual molding operation. These catalysts may be direct-acting (that is, capable of accelerating the reaction at all times) or they may be latent (active mainly when a certain temperature is reached). To prepare molding compositions, the initial urea-aldehyde reaction can be carried out in an alkaline medium, subsequent addition of acid controlling the hydrogen ion concentration. During the molding, an added latent catalyst liberates acid and effects the final hardening.

The mechanisms (2) of the condensation of phenol-formaldehyde have not been ascertained in all their ramifications. Some important facts have, however, been established.

1. The initial reaction of phenols and formaldehyde results in the formation of compounds of the alcohol type in the presence of a basic catalyst or of the diarylmethane type in the presence of an acid catalyst.

2. These compounds react to form extended molecules which may be regarded as joined benzyl groups possessing oxygen or carbon linkages.

3. The chains, particularly in the presence of some slight excess of formaldehyde and a basic catalyst, can be transformed irreversibly into insoluble material, most probably be polymeric change.

Baekeland (2) viewed the phenol formaldehyde reaction as a condensation and polymerization which takes place in three stages, the resinous materials formed being respectively termed initial condensation product A, intermediate condensation product B, and final condensation product C. Under ordinary conditions, A may be liquid, pasty or solid. B is an insoluble solid which swells upon addition of acetone, phenol, or terpineol. B can be melted or softened by heat a limited number of times before it is converted into C, which is infusible and indifferent to all solvents.

Experimental Procedure

One-sixteenth inch yellow birch veneer was used throughout the entire procedure. The veneer was selected for straightness of grain, smoothness, and absence of decay. All the veneer was conditioned under controlled relative humidity of 30 percent, making the moisture content of the wood about 6 percent. After reaching moisture equilibrium, the veneer was impregnated by the hot-and-cold bath (3) method with the following chemicals to give absorptions of approximately 3 to 5 pounds of anhydrous chemical per cubic foot of wood:

1. Monoammonium phosphate
2. Diammonium phosphate
3. Mixture: 2 parts of diammonium phosphate
1 part of monoammonium phosphate
4. Ammonium sulfate
5. Boric acid
6. Borax
7. Ammonium sulfamate

The absorption of approximately 5 pounds of anhydrous chemical per cubic foot was obtained by treating the veneer for 4 hours at a hot-bath temperature of

90° C. to 93° C. in a 15-percent chemical solution and then cooling to room temperature. The absorption of approximately 3 pounds of anhydrous chemical per cubic foot was obtained by treating the veneer for 3 hours at a hot-bath temperature of 90° C. to 95° C. in a 10-percent chemical solution and cooling to room temperature.

Table 1 shows the actual absorptions of anhydrous chemical per cubic foot of wood calculated from weights of the veneer before and after treatment.

Previous tests (3) on fire-proofed wood showed that absorptions of 3 to 5 pounds of anhydrous chemical per cubic foot of wood give satisfactory fire retardance.

The treated veneer--except that used for gluing with phenolic glue film, which was conditioned to 65 percent relative humidity at 80° F.--was conditioned to approximate equilibrium moisture content at 30 percent relative humidity and 80° F. Equilibrium between wood and humidity was reached in 1 week by stickering the veneer and the use of fans to give accelerated circulation of air.

All panels were glued to make a balanced crossbanded construction of 3 plies; that is, the grain of each successive layer of veneer was at right angles to the layer preceding it. This balanced construction resists the tendency of wood to shrink or swell with changes in moisture content.

In the course of the experimental procedure, 7 glues were used to glue veneer treated with 7 different fire-retardant chemicals. Two different impregnations were made with each chemical, plus an untreated control set, for each glue, making a total of 15 different treatments. Five panels were made of each of the 15 treatments glued with each of the 7 glues making a total of 75 panels for each glue and a grand total of 525 panels. Ten test specimens were cut from each panel, making a total of 5,250 plywood test specimens.

In all cases, the gluing conditions used were those that had been found by testing to produce satisfactory bonds on untreated veneer.

After gluing, the panels--except those glued with phenolic glue film, which were placed in the 65 percent relative humidity room--were again brought to equilibrium moisture content at 30 percent relative humidity before being sawed into standard plywood shear test specimens (5) for testing. Five test specimens from each panel were tested dry and 5 were tested wet after soaking in water at room temperature for 48 hours. The plywood specimens were tested in a cement-briquette testing machine (5) which is provided with special grips. Each specimen was subjected to tension and the failure was principally in shear. The breaking load and character of failure were recorded.

A study of the effect of the chemicals on the pH of the glue was carried out by mixing the freshly prepared glue with each chemical. The quantity of chemical added was varied to represent the amount with which the glue would come in contact in veneer which had approximately 5 to 3 pounds of chemical per cubic

foot of wood. These values were calculated by assuming the average penetration of glue into the birch surface to be 1/64 inch, or 1/32 inch per glue line (the glue penetrates two surfaces). On this assumption, when the glue spread is 25 grams per square foot of glue line, the ratio of the amount of glue to the amount of chemical in a 5-pound absorption would be 25 grams of glue to 2.618 grams of anhydrous chemical. The ratio when veneer having a 3-pound absorption of chemical is glued would be 25 grams of glue to 1.753 grams of anhydrous chemical.

Mixtures of these compositions were prepared for each chemical with each glue and the pH determined with a glass electrode. The pH values for cold-setting resins were determined 10 minutes after mixing and those for hot-setting resins 30 minutes after mixing.

Samples of each mixture were placed in the constant-temperature room at 80° F. to determine the working life for each.

The results on shearing strength, wood failure, change in pH of the glue, and working life of each glue obtained when each kind of treated veneer was glued with each glue are tabulated in tables 2 to 14. A summary of the relative success of gluing the different treated veneer with each adhesive is shown in table 15.

Summary and Discussion

1. The impregnation of chemical into the veneer made the wood stiffer and more brittle. The salts which had the greatest effect in this respect were borax and boric acid. The veneer treated with these chemicals was too stiff and brittle to run through the mechanical glue spreader without causing cracking and splitting of the wood. All the panels of borax and boric acid treatments had to be spread by hand.

2. The cold-setting urea-resin, (tables 2 and 3), may be used to glue veneer treated with all of the chemicals used, except borax. Borax, being quite alkaline in solution, increased the pH of the glue mixture well into the alkaline side, where the primary condensation product, dimethylolurea will remain in the liquid state for an indefinite period of time.

3. Results with the hot-setting urea glue on treated veneer (tables 4 and 5) were consistently poor except with ammonium sulfate treatments which showed possibilities of permitting a successful bond. [The salts that decreased the pH of the glue caused a very definite shortening of the working life, which resulted in partially cured glue before pressure and heat were applied to the panel. The initial pH of 8.9 of the untreated glue gives evidence of the presence of a latent catalyst which evolves an acid when a certain temperature is reached. The addition of fire-retardant chemicals neutralizes the latent catalyst and polymerization is partially completed before pressure is applied. The presence of borax neutralized the acid of the catalyst as it was evolved when heated, and the glue mixture remained alkaline, which prevented further polymerization of the glue.]

Urea is Acid Setting Glue

4. The fire-retarding chemicals had a similar effect on the hot-press urea-formaldehyde bag-molding glue with a latent catalyst (tables 6 and 7).

5. The curves (figures 1, 2, and 3) showing the effect of pH on the working life of the three urea-resin glues used in this work indicate, in general, that an increase in acidity should shorten the working life. Points on the graph representing values of working life and pH for mixtures of ammonium sulfamate and boric acid do not lie near the curve. On the three curves, the effect is the same; namely, that boric acid and ammonium sulfamate seem to have some catalytic effect on the working life of the glue, as evidenced by the fact that the working life is increased in comparison with other glue mixtures having approximately the same pH. This effect may be due to a single ion or a combination of ions.

6. The cold-press phenolic resin glue (tables 8 and 9) was very much affected by fire-retardant chemicals, producing poor bonds for each chemical treatment. The treatments with monoammonium phosphate, diammonium phosphate, a mixture of the two, and ammonium sulfate greatly increased the working life. Boric acid and ammonium sulfamate treatments produced unsuccessful bonds despite relatively unchanged working life. Bonds of borax-treated veneer failed completely because the decrease of acidity was too great and polymerization occurred immediately.

7. The results obtained when treated wood was glued with a hot-press phenolic resin glue (tables 10 and 11), showed that treatments with borax, boric acid, and ammonium sulfate produced relatively poor bonds. The bond strength on veneer impregnated with the other chemicals was fair, and it is possible that the treated wood may be more successfully bonded if the glue formula or the gluing conditions are revised.

8. Only veneer treated with monoammonium phosphate and ammonium sulfamate could be bonded with the hot-setting phenolic resin glue of tables 12 and 13, to produce a joint of average strength.

9. The results obtained when treated wood was glued with the phenolic film glue (table 14) definitely indicated this glue to be the best of those tried for gluing fire-proofed veneer although a good joint was not obtained with veneer treated with borax and boric acid.

10. In general, borax and boric acid treatment caused the most trouble in attempts to get a successful bond. This difficulty may be ascribed to the relatively high basicity of borax and the high acidity of boric acid as well as a possible effect produced by the boron ion in urea-formaldehyde resins.

11. The actual chemical effects of fire-retardant chemicals on phenol-formaldehyde are difficult to distinguish because of the complexity of the polymerization reaction and the variability of composition of modified phenol resins.

12. In general, the resistance of urea-formaldehyde and phenol-formaldehyde glues to water was decreased by the presence of fire-retardant chemicals.

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Table 1.--Absorption of anhydrous chemical

Chemical	Pounds of anhydrous chemical per cu.ft. (4-hour treatment)	Pounds of anhydrous chemical per cu.ft. (3-hour treatment)
Monoammonium phosphate	4.8	3.1
Diammonium phosphate	5.4	3.5
Mixture: 2 parts diammonium phosphate 1 part monoammonium phosphate	4.4	3.6
Ammonium sulfate	4.3	2.7
Boric acid	5.3	3.6
Borax	5.5	4.1
Ammonium sulfamate	6.4	3.3

Table 2.--Dry and wet shear strengths of birch plywood treated with different fire-retardant salts glued[1] with a cold-setting, urea resin glue

Salts	Absorption of anhydrous salt	Test values[2]			
		Dry[3]		Wet[4]	
		Strength	Wood failure	Strength	Wood failure
	Lb. per cu. ft. of wood	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Monoammonium phosphate	4.8	339	38	262	4
	3.1	376	60	311	17
Diammonium phosphate	5.4	323	37	266	24
	3.5	336	20	300	2
Mixture: 2 parts diammonium phosphate 1 part monoammonium phosphate	4.4	397	79	303	25
	3.6	374	39	217	2
Ammonium sulfate	4.3	349	15	263	0
	2.7	334	14	260	0
Boric acid	5.3	329	25	228	1
	3.6	341	45	228	4
Borax	5.5	0	0	0	0
	4.1	0	0	0	0
Ammonium sulfamate	6.4	318	55	182	0
	3.3	323	43	182	0
Untreated	---	371	33	296	8

[1] Gluing conditions; pressure, 150 pounds per square inch; assembly time, 10 minutes; spread, 20-25 grams per square foot; time in press, overnight; temperature, 75° F.

[2] Each value is the average of the results of 25 specimens, 5 taken from each panel.

[3] Tested after reaching equilibrium in 30 percent relative humidity room.

[4] Tested after soaking in water at room temperature for 48 hours.

Table 3.--Effect of fire-retardant chemicals on the pH and working life of cold-setting urea-resin glue (see table 2)

Chemical	pH	Change in pH	Working life at 80° F. in hours
Monoammonium phosphate			
5 lb. abs. per cu. ft.	4.5	-.95	1.75
3 lb. abs. per cu. ft.	4.59	-.86	1.5
Diammonium phosphate			
5 lb. abs. per cu. ft.	6.9	+1.45	5.5
3 lb. abs. per cu. ft.	6.5	+1.05	5.0
Mixture of 2 parts diammonium phosphate and 1 part monoammonium phosphate			
5 lb. abs. per cu. ft.	6.2	+.75	2.5
3 lb. abs. per cu. ft.	6.01	+.56	2.5
Ammonium sulfate			
5 lb. abs. per cu. ft.	5.08	-.37	4.5
3 lb. abs. per cu. ft.	5.08	-.37	4.25
Boric acid			
5 lb. abs. per cu. ft.	4.32	-1.13	3.5
3 lb. abs. per cu. ft.	4.38	-1.07	3.0
Borax			
5 lb. abs. per cu. ft.	8.46	+3.01	Indefinite[1]
3 lb. abs. per cu. ft.	8.25	+2.8	Indefinite[1]
Ammonium sulfamate			
5 lb. abs. per cu. ft.	5.68	+2.4	16.5
3 lb. abs. per cu. ft.	5.60	+.15	10.5
Untreated	5.45		2.75

[1] Did not solidify.

Table 4.--Dry and wet shear strengths of birch plywood treated with different fire-retardant salts and glued[1] with hot-setting, urea-resin glue

Salts	Absorption of anhydrous salt	Test values[2]			
		Dry[3]		Wet[4]	
		Strength	Wood failure	Strength	Wood failure
	Lb. per cu. ft. of wood	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Monoammonium phosphate	4.8	215	4	168	2
	3.1	211	22	207	10
Diammonium phosphate	5.3	256	23	231	6
	3.5	237	22	244	12
Mixture: 2 parts diammonium phosphate 1 part monoammonium phosphate	4.4	218	11	180	11
	3.6	258	7	267	15
Ammonium sulfate	4.3	353	48	360	25
	2.7	367	42	380	47
Boric acid	5.3	68	2	48	0
	3.6	224	31	230	19
Borax	5.5	0	0	0	0
	4.1	472	73	155	17
Ammonium sulfamate	6.4	237	17	177	2
	3.3	275	21	284	12
Untreated	---	357	22	428	48

[1] Gluing conditions: pressure, 150 pounds per square inch; assembly time, 20 to 23 hours; spread, 20 to 25 grams per square foot, time in press, 3-1/2 minutes; temperature, 260° F.

[2] Each value is the average of the results of 25 specimens, 5 taken from each panel.

[3] Tested after reaching equilibrium in 30 percent relative humidity room.

[4] Tested after soaking in water at room temperature for 48 hours.

Table 5.--Effect of fire-retardant chemicals on the pH and working life of a hot-setting urea-resin glue (see table 4)

Chemical	pH	Change in pH	Working life at 80° F. in hours
Monoammonium phosphate			
5 lb. abs. per cu. ft.	5.95	-2.95	4.0
3 lb. abs. per cu. ft.	6.29	-2.7	4.0
Diammonium phosphate			
5 lb. abs. per cu. ft.	7.08	-1.88	4.5
3 lb. abs. per cu. ft.	7.29	-1.61	5.0
Mixture of 2 parts diammonium phosphate and 1 part monoammonium phosphate			
5 lb. abs. per cu. ft.	6.7	-2.2	4.0
3 lb. abs. per cu. ft.	7.0	-1.9	5.0
Ammonium sulfate			
5 lb. abs. per cu. ft.	8.81	- .09	20
3 lb. abs. per cu. ft.	8.81	- .09	22
Boric acid			
5 lb. abs. per cu. ft.	6.53	-2.73	22
3 lb. abs. per cu. ft.	7.4	-1.5	27
Borax			
5 lb. abs. per cu. ft.	9.13	+ .23	Indefinite[1]
3 lb. abs. per cu. ft.	9.01	+ .11	Indefinite[1]
Ammonium sulfamate			
5 lb. abs. per cu. ft.	8.5	- .4	36
3 lb. abs. per cu. ft.	8.58	- .38	36
Untreated	8.9		36

[1] Did not solidify.

Table 6.--Dry and wet shear strengths of birch plywood treated with different fire-retardant chemicals and glued[1] with a hot-press, bag-molding, urea-resin glue

Salts	Absorption of anhydrous salt	Test values[2]			
		Dry[3]		Wet[4]	
		Strength	Wood failure	Strength	Wood failure
	Lb. per cu. ft. of wood	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Monoammonium phosphate	4.8	173	3	119	2
	3.1	159	3	136	2
Diammonium phosphate	5.3	148	5	130	2
	3.5	174	1	149	3
Mixture:					
2 parts diammonium phosphate 1 part monoammonium phosphate	4.4	206	11	191	9
	3.6	250	16	224	9
Ammonium sulfate	4.3	116	0	104	0
	2.7	144	0	135	0
Boric acid	5.3	67	1	64	0
	3.6	156	12	139	6
Borax	5.5	264	0	0	0
	4.1	152	0	0	0
Ammonium sulfamate	6.4	335	23	255	6
	3.3	308	5	248	0
Untreated	---	374	60	51	5

[1] Gluing conditions: presure, 150 pounds per square inch; assembly time, 3 days, spread, 20-25 grams per square foot; time in press, 7 minutes; temperature, 285° F.

[2] Each value is the average of the results of 25 specimens, 5 taken from each panel.

[3] Tested after reaching equilibrium in 30 percent relative humidity room.

[4] Tested after soaking in water at room temperature for 48 hours.

Table 7.--Effect of fire-retardant chemicals on pH and working life of a bag-molding, urea-resin glue (see table 6)

Chemical	pH	Change in pH	Working life at 80° F. in hours
Monoammonium phosphate			
5 lb. abs. per cu. ft.	6.69	-1.16	9.0
3 lb. abs. per cu. ft.	6.69	- .86	17
Diamonium phosphate			
5 lb. abs. per cu. ft.	6.73	- .82	7.0
3 lb. abs. per cu. ft.	7.09	- .46	15
Mixture of 2 parts of diammonium phosphate and 1 part monoammonium phosphate			
5 lb. abs. per cu. ft.	6.75	- .80	8.0
3 lb. ab.s per cu. ft.	6.99	- .56	16
Ammonium sulfate			
5 lb. abs. per cu. ft.	7.4	- .15	42
3 lb. abs. per cu. ft.	7.35	- .20	42
Boric acid			
5 lb. abs. per cu. ft.	5.43	-2.12	24
3 lb. abs. per cu. ft.	5.59	-1.69	20
Borax			
5 lb. abs. per cu. ft.	8.11	+1.56	Indefinite[1]
3 lb. abs. per cu. ft.	8.15	+1.60	Indefinite[1]
Ammonium sulfamate			
5 lb. abs. per cu. ft.	7.29	- .29	60
3 lb. abs. per cu. ft.	7.38	- .17	60
Untreated	7.55		60

[1] Great increase in viscosity.

Table 8.--Dry and wet shear strengths of birch plywood treated with different fire-retardant chemicals and glued[1] with a cold-press, phenolic-resin glue

Salts	Absorption of anhydrous salt	Test values[2]			
		Dry[3]		Wet[4]	
		Strength	Wood failure	Strength	Wood failure
	Lb. per cu. ft. of wood	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Monoammonium phosphate	4.8	197	0	40	0
	3.1	188	0	10	0
Diammonium phosphate	5.4	80	0	0	0
	3.5	106	0	0	0
Mixture:					
2 parts diammonium phosphate	4.4	131	0	0	0
1 part monoammonium phosphate	3.6	116	0	0	0
Ammonium sulfate	4.3	235	2	125	0
	2.7	218	1	142	0
Boric acid	5.3	268	7	137	0
	3.6	295	13	179	0
Borax	5.5	0	0	0	0
	4.1	102	0	0	0
Ammonium sulfamate	6.4	220	2	109	0
	3.3	198	1	97	0
Untreated	---	418	77	342	97

[1]Gluing conditions: pressure, 150 pounds per square inch; assembly time, 10 minutes; spread, 20-25 grams per square foot; time in press, overnight; temperature, 80° F.

[2]Each value is the average of the results of 25 specimens, 5 taken from each panel.

[3]Tested after reaching equilibrium in 30 percent relative humidity room.

[4]Tested after soaking in water at room temperature for 48 hours.

Table 9.--Effect of fire-retardant chemicals on pH and working life of a cold-setting, phenolic-resin glue (see table 8)

Chemical	pH	Change in pH	Working life at 80° F. in hours
Monoammonium phosphate			
5 lb. abs. per cu. ft.	1.57	+.68	64
3 lb. abs. per cu. ft.	1.50	+.62	56
Diammonium phosphate			
5 lb. abs. per cu. ft.	1.14	+.26	23.5
3 lb. abs. per cu. ft.	1.08	+.20	22.5
Mixture of 2 parts diammonium phosphate and 1 part monoammonium phosphate			
5 lb. abs. per cu. ft.	1.58	+.70	48
3 lb. abs. per cu. ft.	1.63	+.75	40
Ammonium sulfate			
5 lb. abs. per cu. ft.	1.2	+.32	23
3 lb. abs. per cu. ft.	1.12	+.24	22
Boric acid			
5 lb. abs. per cu. ft.	1.29	+.41	3
3 lb. abs. per cu. ft.	1.15	+.27	4
Borax			
5 lb. abs. per cu. ft.	1.7	+.82	Solidified immediately[1]
3 lb. abs. per cu. ft.	1.61	+.73	Solidified immediately[1]
Ammonium sulfamate			
5 lb. abs. per cu. ft.	1.2	+.32	3
3 lb. abs. per cu. ft.	1.0	+.12	3
Untreated	.88		4

[1] Formaldehyde given off.

Table 10.--Dry and wet shear strengths of birch plywood treated with different fire-retardant chemicals and glued[1] with a hot-press, phenolic-resin glue

Salts	Absorption of anhydrous salt	Test values[2]			
		Dry[3]		Wet[4]	
		Strength	Wood failure	Strength	Wood failure
	Lb. per cu. ft. of wood	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Monoammonium phosphate	4.8	299	14	245	3
	3.1	269	5	255	1
Diammonium phosphate	5.4	279	12	232	3
	3.5	242	9	196	4
Mixture:					
2 parts diammonium phosphate	4.4	257	4	173	0
1 part monoammonium phosphate	3.6	288	13	224	4
Ammonium sulfate	4.3	187	0	64	0
	2.7	192	11	134	3
Boric acid	5.3	0	0	0	0
	3.6	208	22	167	0
Borax	5.5	209	24	43	0
	4.1	0	0	0	0
Ammonium sulfamate	6.4	280	16	199	2
	3.3	285	3	217	1
Untreated	---	265	6	346	14

[1] Gluing conditions: pressure, 150 pounds per square inch; assembly time, 16-24 hours; spread, 20-25 grams per square foot; time in press, 8 minutes; temperature, 330° F.

[2] Each value is the average of the results of 25 specimens, 5 taken from each panel.

[3] Tested after reaching equilibrium in 30 percent relative humidity room.

[4] Tested after soaking in water at room temperature for 48 hours.

Table 11.--Effect of fire-retardant chemicals on pH and working life of a hot-press, phenolic-resin glue (see table 10)

Chemical	pH	Change in pH	Working life at 80° F. in hours[1]
Monoammonium phosphate			
5 lb. abs. per cu. ft.	6.52	-3.44	
3 lb. abs. per cu. ft.	5.80	-4.61	
Diammonium phosphate			Increase
5 lb. abs. per cu. ft.	7.51	-2.45	
3 lb. abs. per cu. ft.	7.80	-2.16	
Mixture of 2 parts diammonium phosphate and 1 part monoammonium phosphate			Increase
5 lb. abs. per cu. ft.	6.99	-2.97	
3 lb. abs. per cu. ft.	7.21	-2.75	
Ammonium sulfate			Increase
5 lb. abs. per cu. ft.	8.18	-1.78	
3 lb. abs. per cu. ft.	8.42	-1.54	
Boric acid			Increase
5 lb. abs. per cu. ft.	6.72	-3.24	
3 lb. abs. per cu. ft.	7.28	-2.68	
Borax			
5 lb. abs. per cu. ft.	9.23	- .73	
3 lb. abs. per cu. ft.	9.28	- .68	
Ammonium sulfamate			
5 lb. abs. per cu. ft.	8.28	-1.68	
3 lb. abs. per cu. ft.	8.41	-1.55	
Untreated	9.96		

[1] Exact working life difficult to obtain because of gelatinous consistency of glue.

Table 12.--Dry and wet shear strengths of birch plywood treated with different fire-retardant chemicals and glued[1] with a hot-press, bag-molding phenolic-resin glue

Salts	Absorption of anhydrous salt	Test values[2]			
		Dry[3]		Wet[4]	
		Strength	Wood failure	Strength	Wood failure
	Lb. per cu. ft. of wood	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Monoammonium phosphate	4.8	378	49	411	58
	3.1	370	31	414	71
Diammonium phosphate	5.4	213	0	260	3
	3.5	233	0	317	2
Mixture: 2 parts diammonium phosphate 1 part monoammonium phosphate	4.4	206	0	283	1
	3.6	258	3	328	6
Ammonium sulfate	4.3	247	0	332	0
	2.7	244	0	275	0
Boric acid	5.3	0	0	0	0
	3.6	113	8	108	0
Borax	5.5	0	0	0	0
	4.1	0	0	0	0
Ammonium sulfamate	6.4	297	14	382	21
	3.3	298	16	330	10
Untreated	---	344	9	446	35

[1]Gluing conditions: pressure, 150 pounds per square inch; assembly time, 13-14 days; spread, 20-25 grams per square foot, time in press, 10 minutes; temperature, 310° F.

[2]Each value is the average of the results of 25 specimens, 5 taken from each panel.

[3]Tested after reaching equilibrium in 30 percent relative humidity room.

[4]Tested after soaking in water at room temperature for 48 hours.

Table 13.--Effect of fire-retardant chemicals on pH and working life of a bag-molding phenolic-resin glue (see table 12)

Chemical	pH	Change in pH	Working life at 80° F. in hours	Remarks
Monoammonium phosphate				
5 lb. abs. per cu. ft.	3.18	+.87	0	Precipitation within 10 minutes
3 lb. abs. per cu. ft.	3.08	+.77	0	
Diammonium phosphate				
5 lb. abs. per cu. ft.	6.3	+3.99	0	Precipitation within 10 minutes
3 lb. abs. per cu. ft.	6.1	+3.79	0	
Mixture of 2 parts diammonium phosphate and 1 part monoammonium phosphate				
5 lb. abs. per cu. ft.	5.68	+3.37	0	Precipitation within 10 minutes
3 lb. abs. per cu. ft.	5.6	+3.37	0	
Ammonium sulfate				
5 lb. abs. per cu. ft.	2.55	+.24	0	Precipitation within 10 minutes
3 lb. abs. per cu. ft.	2.6	+.29	0	
Boric acid				
5 lb. abs. per cu. ft.	1.9	-.41	Did not solidify	No precipitate
3 lb. abs. per cu. ft.	1.99	-.32		
Borax				
5 lb. abs. per cu. ft.			Hardened immediately	No precipitate
3 lb. abs. per cu. ft.				
Ammonium sulfamate	2.6	+.29	0	Precipitation within 10 minutes
5 lb. abs. per cu. ft.	2.51	+.20	0	
Untreated	2.31		Did not solidify	

Table 14.--Dry and wet shear strengths of birch plywood treated with different fire-retardant chemicals and glued[1] with a hot-press, phenolic-resin, film glue

Salts	Absorption of anhydrous salt	Test values[2]			
		Dry[3]		Wet[4]	
		Strength	Wood failure	Strength	Wood failure
	Lb. per cu. ft. of wood	Lb. per sq. in.	Percent	Lb. per sq. in.	Percent
Monammonium phosphate	4.8	396	24	428	32
	3.1	365	26	434	57
Diammonium phosphate	5.4	382	38	372	46
	3.5	393	22	399	33
Mixture					
2 parts diammonium phosphate	4.4	399	22	462	54
1 part monoammonium phosphate	3.6	400	9	450	39
Ammonium sulfate	4.3	387	4	381	3
	2.7	349	6	387	35
Boric acid	5.3	264	34	90	0
	3.6	278	54	137	0
Borax	5.5	346	41	139	0
	4.1	209	3	34	0
Ammonium sulfamate	6.4	381	2	398	11
	6.3	391	44	393	48
Untreated	---	376	8	455	36

[1]Gluing conditions: pressure, 200 pounds per square inch; spread, 1 sheet; time in press, 10 minutes; temperature, 310° F.

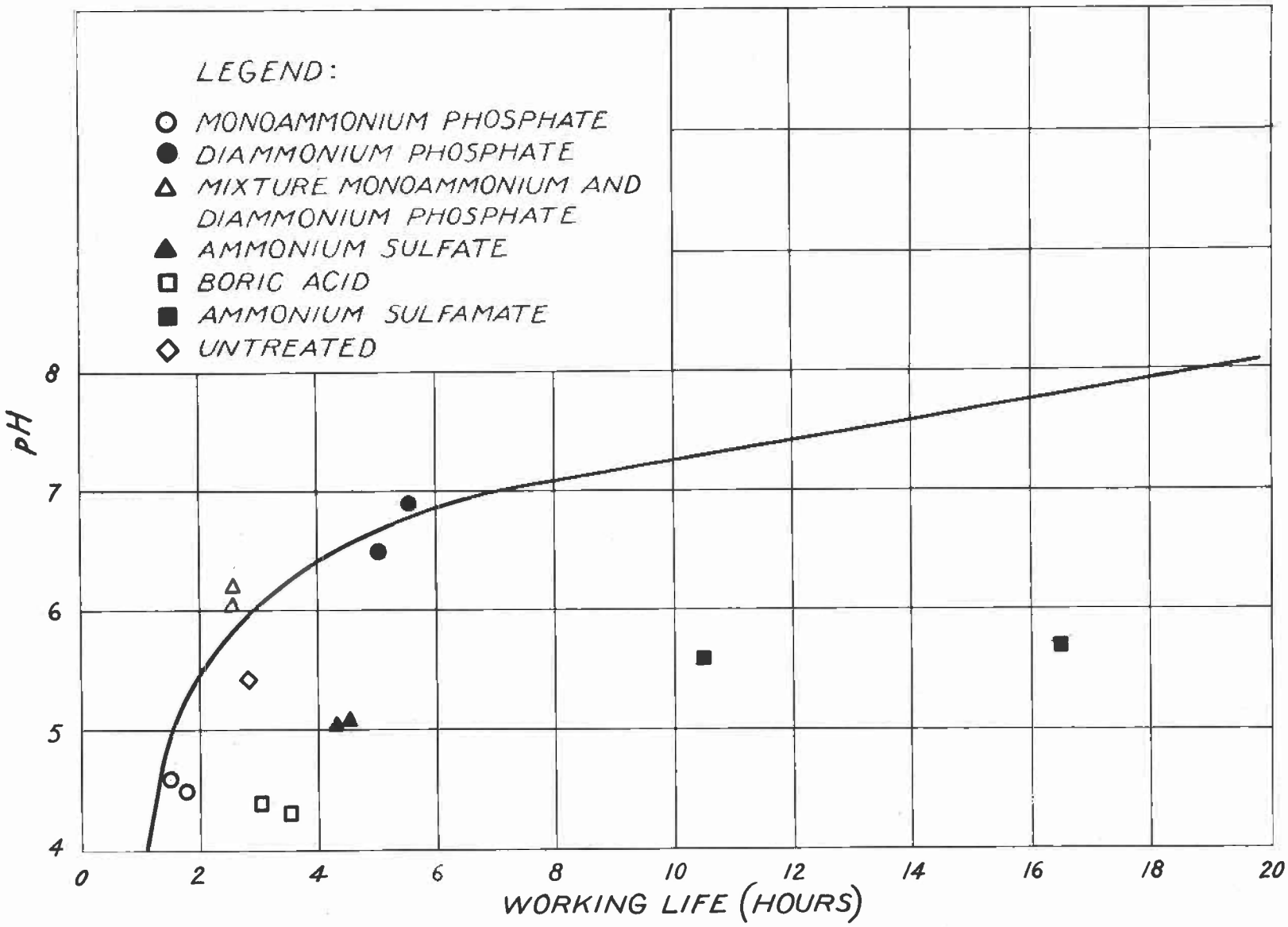
[2]Each value is the average of the results of 25 specimens, 5 taken from each panel.

[3]Tested after reaching equilibrium in 65 percent relative humidity room.

[4]Tested after soaking in water at room temperature for 48 hours.

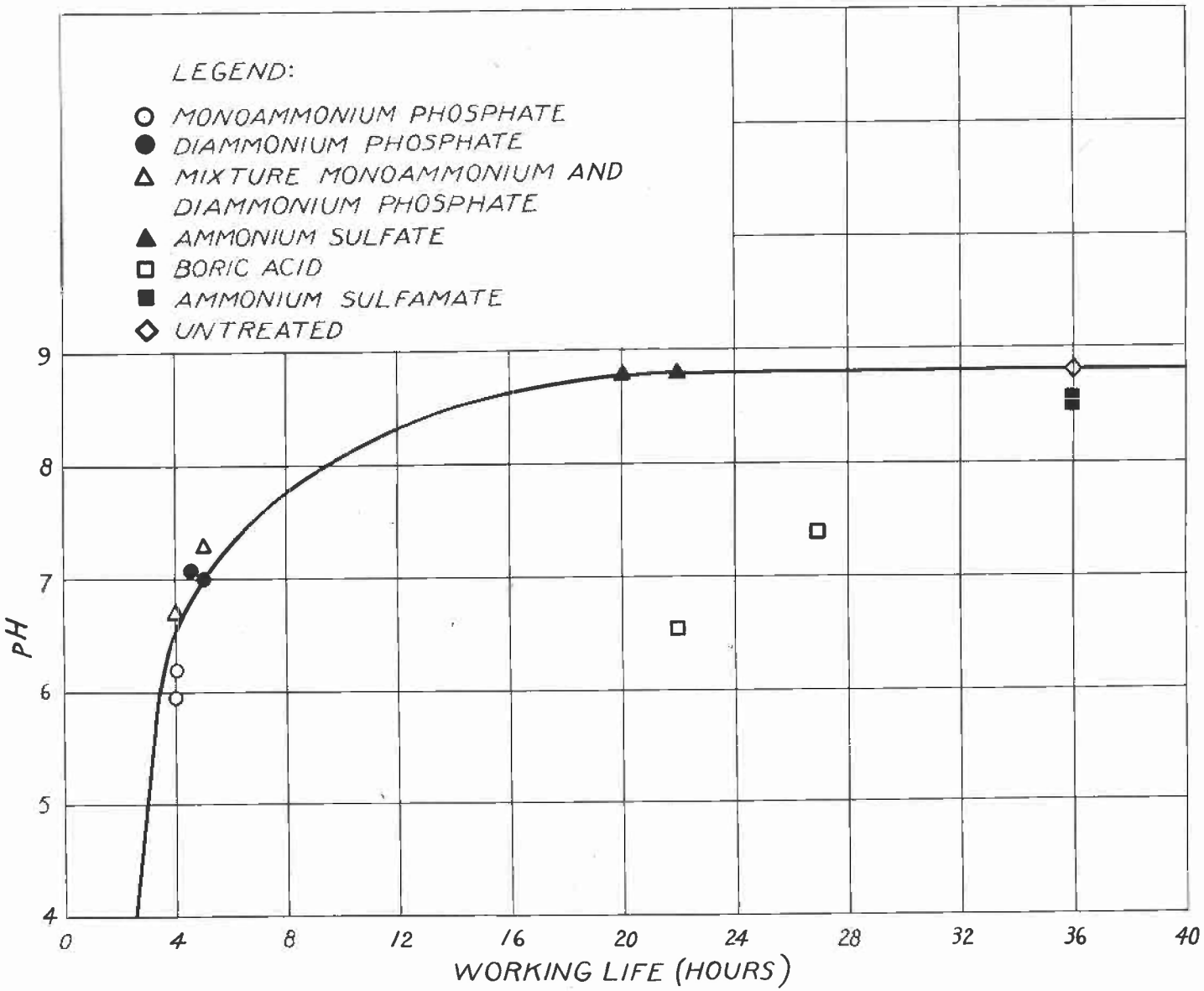
Table 15.--Summary of the relative success of gluing treated veneer with urea- and phenol-formaldehyde glues

Glue	Mono-ammonium phosphate	Di-ammonium phosphate	Mixture 2 parts diammonium sulfate 1 part mono-ammonium phosphate	Ammonium sulfate	Boric acid	Borax	Ammonium sulfamate
Cold-setting urea	Fair	Fair	Fair	Fair	Fair	Failure	Fair
Hot-setting urea	Poor	Poor	Poor	Fair	Poor	Poor	Poor
Bag-molding urea	Poor	Poor	Poor	Poor	Poor	Failure	Fair
Cold-setting phenol	Very poor	Very poor	Very poor	Poor	Poor	Failure	Poor
Hot-setting phenol	Fair	Fair	Fair	Poor	Very poor	Very poor	Fair
Bag-molding phenol	Good	Poor	Poor	Poor	Failure	Failure	Fair
Phenolic film	Good	Good	Good	Fair	Poor	Poor	Good



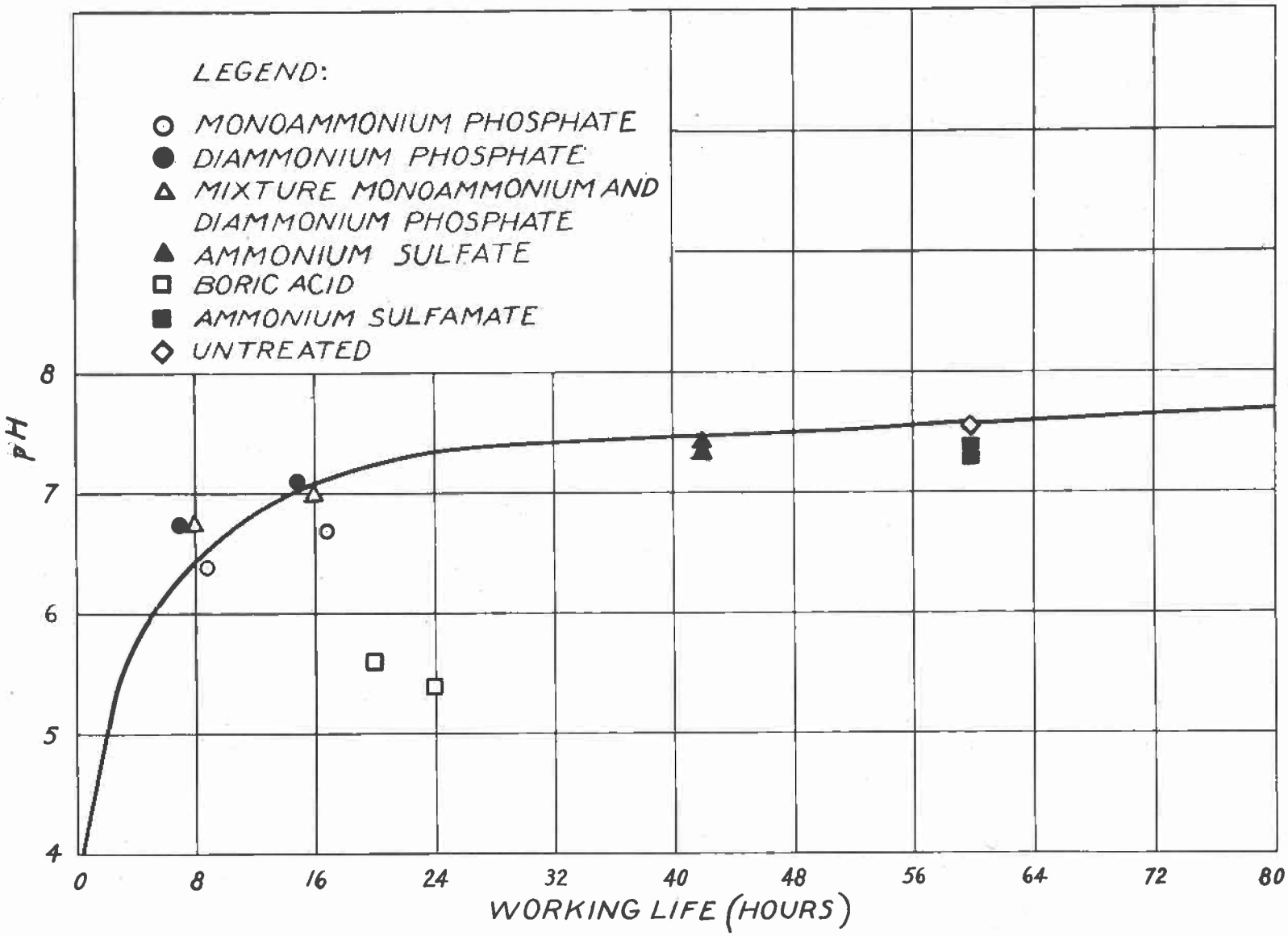
Z M 45789 F

Figure 1.--Relation of pH to the working life at 80° F. of a cold-setting urea glue.



Z M 45790 F

Figure 2.--Relation of pH to the working life at 80° F. of a hot-setting, urea glue.



Z M 45791 F

Figure 3.--Relation of pH to the working life at 80° F. of a bag-molding urea glue.

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