Fire-Retardant Coatings for Fabric-Covered Aircraft

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Simulated power-plant fire tests of doped fabrics coated with fire-retardant coatings, conducted under wind-tunnel conditions, demonstrate that it is possible to increase the critical time interval between the instant of first contact of fire with fabric and the instant of fabric destruction, from the present value of 2 seconds with cellulose nitrate dope or 6 seconds with cellulose acetate butyrate dope to 12 seconds with a fire-retardant coating applied over cellulose acetate butyrate dope. A laboratory method for the quick evaluation of relative performance of fire-retardant coatings is described; this test will facilitate the further development of fire-retardant coatings. The protective action of fire-retardant coatings on cellulose nitrate dope is too small to be of any value. The results of outdoor exposure tests reveal several fire-retardant coating systems with good weathering characteristics which are recommended for further development. The use of a mixture of boric acid and borax as fabric impregnant, while effective as a fire retardant, has a deleterious effect on adhesion of dope to fabric which is apparent on outdoor exposure.

AIRCRAFT power-plant fire tests conducted by the Civil Aeronautics Administration at the National Bureau of Standards in 1943 emphasized the need for providing fire-retardant coatings for doped fabric surfaces. Although complete fireproofing is not feasible or perhaps not even possible, substantial protection can be afforded by providing a coating which will delay destruction of the fabric, after the outbreak of a fire, beyond the time interval necessary for extinguishment. Therefore, a joint program of the Civil Aeronautics Administration and National Bureau of Standards looking toward the development of fire-retardant coatings for doped aircraft fabrics was set up.

Fabrics doped with cellulose acetate butyrate do not present the fire hazard encountered with fabrics doped with cellulose nitrate. However, even the slow-burning butyrate dope would not be satisfactory in power-plant fires in which the doped fabric is likely to be in continuous contact with flame for several seconds.

No fire-retardant film-forming materials are known which tauten airplane fabrics as effectively and as permanently as do dopes based on cellulose derivatives. Furthermore, the addition of fire-retardant resins to cellulose derivatives has little effect in increasing their fire retardance but has a serious effect on tautness as shown by Kline (*1*). Therefore, at the outset of this program it was decided to provide additional fire resistance to doped fabric by applying a fire-retardant surface coating. The essential properties required in the surface coating are as follows: (1) fire retardancy, (2) good adhesion to doped surfaces, (3) minimum effect on the tautness of the substrate-doped fabric, (4) applicability by usual coating techniques, (5) flexibility, (6) resistance to weathering equivalent to that of currently used dopes, (7) resistance to action of gasoline, oil, and ethylene glycol, and (8) aerodynamic smoothness.

MATERIALS INVESTIGATED

Table I describes the materials investigated. Materials which have been most successfully used in fire-retardant coatings are (*a*) film-forming substances which, on pyrolysis, give off large quantities of noncombustible gases and (*b*) pigments which function by the production of noncombustible gases or by the formation of a protective glaze which excludes oxygen (*2*). Since most of the film-forming materials must be plasticized, it is desirable to incorporate as much fire retardancy into the film as possible by using fire-retardant plasticizers; a number were included in this investigation. In addition, several commercial preparations recommended by manufacturers as flame-resistant coatings were evaluated for comparison.

DOPED FABRIC TEST PANELS

Wood frames were used for those doped fabric assemblies which were to be tested in the full-scale wind-tunnel fire tests at Indianapolis, and metal frames for panels to be placed on outdoor exposure in Washington, D. C. Grade A airplane fabric, weighing 4 ounces per square yard, was stretched over the 15-inch square frames which had openings 12 inches square. The fabric was then coated with 10% by weight of a mixture of 3 parts of boric acid and 7 parts of borax, applied as a 7% aqueous solution. The purpose was to minimize the tendency for the flame to be propagated under the fabric in the still-air burning test. Four coats of clear cellulose acetate butyrate dope, conforming to Army-Navy Aeronautical Specification AN-D-1, and two coats of pigmented cellulose acetate butyrate dope, conforming to Specification AN-D-2, were applied to the fabric. Dope was applied according to the procedure defined by Navy Aeronautical Specification SR-70e. The total weight of dope applied was about 4.5 ounces per square yard. Fire-retardant coats were sprayed on this basic six-coat system, the number of fire-retardant coats depending upon the tests to which the panel was to be subjected. The weight of each fire-retardant coat was approximately 2 ounces per square yard.

EVALUATION OF FIRE RETARDANCE

STILL-AIR BURNING TEST. It was necessary to select optimum combinations of the fire-retardant materials to serve as a basis for further development. In the initial stages of the investigation the apparatus developed by Brown and described by Kline (*1*) was used. It consists of two parallel steel clamps supported by a steel frame, the distance between the two clamps being adjustable. The specimen to be tested is fastened between the clamps and ignited at one end. The time required for the flame front to travel over a given distance (5 inches), as measured along the clamps between two marks, is recorded with a stop watch. Specimens used in these tests were 3 inches wide and 8 inches long, and were taken from panels with two fire-retardant coats. They differed from the specimens used by Kline in that two rows of 1/8-inch-diameter holes, with centers 1/4 inch apart lengthwise and 2 inches apart crosswise, were punched in the specimen. The purpose of these holes was to provide a constant air supply throughout the test. The apparatus is suitable for either horizontal or vertical burning tests.

MOVING-AIR BURNING TEST. It was soon found that, as the development led to coatings which were more fire retardant, the

TABLE I. MATERIALS INVESTIGATED IN FIRE-RETARDANT COATING DEVELOPMENT

Trade Name	Chemical Classification	Manufacturer
	FILM BASES	
Pliolite	Rubber hydrochloride	Goodyear Tire and Rubber Co.
Insl-X	Chlorinated rubber	Insl-X Co., Inc.
Parlon 125	Chlorinated rubber	Hercules Powder Co. (Inc.)
Parlon R	Chlorinated neoprene	Hercules Powder Co. (Inc.)
Parlon X	Chlorinated polyisoprene	Hercules Powder Co. (Inc.)
Mathieson rubber 153b	Butadiene-dichlorostyrene	Mathieson Alkali Works (Inc.)
Vinylite VYHH	Vinyl chloride acetate	Bakelite Corp.
Resin 256-27	Vinyl chloride acetate	American Resinous Chemicals Corp.
Resin X-124	Vinylidene chloride–acrylonitrile	Dow Chemical Co.
Resin X-120	Vinylidene chloride–vinyl chloride	Dow Chemical Co.
Resin F-120	Vinylidene chloride–acrylonitrile	Dow Chemical Co.
Mathieson plastic 153a	Polydichlorostyrene	Mathieson Alkali Works (Inc.)
Amercoat 1138	Vinyl chloride–vinyl acetate soln. (45% solids)	American Pipe and Construction Co.
Amecco paint	Fire-retardant paint	Amecco Chemicals, Inc.
Pyropex dope	Ethylcellulose dope	Sherwin-Williams Co.
Skylac dope	Cellulose acetate butyrate dope	Monsanto Chemical Co.
	MODIFYING RESINS	
Acryloid C-5	Acrylic resin	Resinous Products and Chemical Co.
Acryloid B-72	Acrylic resin	Resinous Products and Chemical Co.
Acryloid B-75	Acrylic resin	Resinous Products and Chemical Co.
Arochem 345	Alkyd resin	U. S. Industrial Chemicals, Inc.
Arochem 520	Alkyd resin	U. S. Industrial Chemicals, Inc.
Aroclor 5460	Chlorinated diphenyl	Monsanto Chemical Co.
Aroplaz 945	Alkyd resin	U. S. Industrial Chemicals, Inc.
Aroplaz 930	Alkyd resin	U. S. Industrial Chemicals, Inc.
Aropene 700	Phenolic resin	U. S. Industrial Chemicals, Inc.
Bakelite XR-976	Phenolic resin	Bakelite Corp.
Bakelite XR-13630	Phenolic resin	Bakelite Corp.
Beckasol 31	Alkyd resin	Reichhold Chemicals, Inc.
Clorafin 70	Chlorinated paraffin	Hercules Powder Co.
Lewisol 24	Alkyd resin	John D. Lewis Co.
Lewisol 33	Alkyd resin	John D. Lewis Co.
Rezyl 869	Alkyd resin	American Cyanamid Co.
Uformite	Urea-formaldehyde	Resinous Products and Chemical Co.
	PLASTICIZERS	
Aroclor 1254	Chlorinated diphenyl	Monsanto Chemical Co.
.....	Butyl-2-methyl-2-nitropropyl phthalate	Commercial Solvents Corp.
.....	Camphor	E. I. du Pont de Nemours & Co., Inc.
Clorafin 42	Chlorinated paraffin	Hercules Powder Co.
.....	Dibutyl phthalate	U. S. Industrial Chemicals, Inc.
Flexol DOP	Dioctyl phthalate	Carbide and Carbon Chemicals Corp.
.....	Diphenyl phthalate	Eastman Kodak Co.
Dow No. 6	.....	Dow Chemical Co.
Flexol 3GH	Triethylene glycol di-2-ethyl butyrate	Carbide and Carbon Chemicals Corp.
Halowax 4001	Chlorinated paraffin	Union Carbide and Carbon Corp.
Hercolyn	Hydrogenated methyl abietate	Hercules Powder Co. (Inc.)
.....	Hexachloroethane	.....
Salol	Phenyl salicylate	Eastman Kodak Co.
Santicizer B-16	Butyl phthalyl butyl glycolate	Monsanto Chemical Co.
Santicizer M-17	Methyl phthalyl methyl glycolate	Monsanto Chemical Co.
.....	Tricresyl phosphate	Eastman Kodak Co.
.....	Triphenyl phosphate	Eastman Kodak Co.
Rezyl 36-5	Phthalic alkyd soft resin	American Cyanamid Co.
	PIGMENTS	
	Antimony oxide, asbestos fibers, calcium carbonate, magnesium ammonium phosphate, titanium dioxide, zinc borate	

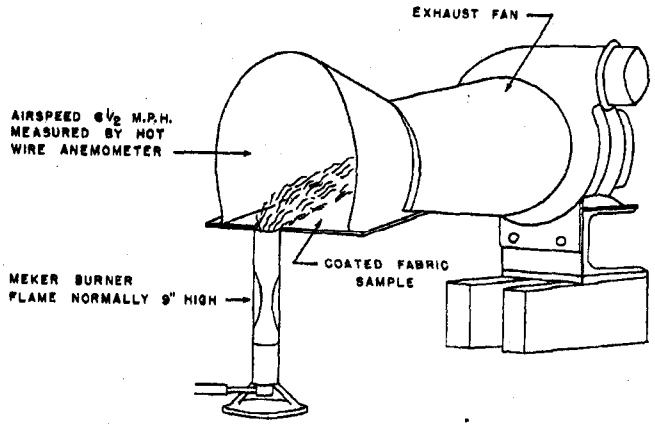

Figure 1. Apparatus for Selecting Doped Fabric Coatings by Moving-Air Burning Test

still-air burning test was inadequate because the coatings were self-extinguishing. A moving-air burning test was developed which permitted evaluation of the more fire-retardant coatings. Figure 1 is a sketch of the apparatus. A small laboratory centrifugal exhaust fan draws air through a funnel-shaped entrance port, which is adapted to accommodate a doped fabric test panel. The doped fabric panel is attached to the bottom of the entrance funnel with the fire-retardant coating on the inside. A Meker burner with air supply adjusted to give a quiet blue flame 9 inches high is placed in such a position with respect to the fabric that the current of air causes the flame to lie on the coated surface. Wind velocity in the center of the entrance port is 6.5 miles per hour, measured with a hot-wire anemometer. The time intervals (1) between flame contact and ignition of coating and (2) between flame contact and charring of the fabric as seen from the outside are measured with a stop watch. For a group of 119 tests of pairs of duplicate samples, the standard deviation of an individual measurement was 1.0 second. The panels used in these tests had two fire-retardant coats.

WIND-TUNNEL BURNING TEST. A steel wing section of Clark Y airfoil was suspended, as shown in Figure 2, at the outlet end of an open-type wind tunnel. A 12-inch-square opening was provided in the center of the span and chord of the lower surface to admit fabric panels. The angle between the plane of the test panel and the axis of the wind tunnel was 0°. The wind tunnel was operated so as to provide an air stream of 70 miles per hour. Just in front of the wing was mounted a spray gun to which were supplied approximately 1.5 gallons per minute of 90-octane aviation gasoline and air at approximately 50 pounds per square inch pressure. The gun introduced a uniform spray of atomized gasoline into the air stream. At zero time the spray was ignited by a spark from a high-tension aircraft spark plug. This provided an envelope of burning gasoline which passed both over and under the airfoil, and ensured continuous contact of the test specimen with flame during the test. The gasoline flow was regulated by a solenoid-type electric valve. The course of the fire was observed by two men on the ground with stop watches and by a motion picture camera aimed at a mirror so oriented in the interior of the wing section as to permit observation of the inside surface of the test panel. A large electric clock with a sweep second hand was placed in the field of view of the camera to provide an auxiliary time scale. The motion picture camera was operated at a speed of sixteen frames per second. One observer noted the time for the destruction of the outer coating, and the second observer noted the time of fabric failure. The destruction of the outer coating was evidenced by pieces of coating being blown away by the wind stream. Failure of the fabric was evidenced by two criteria: To the outside observer the disin-

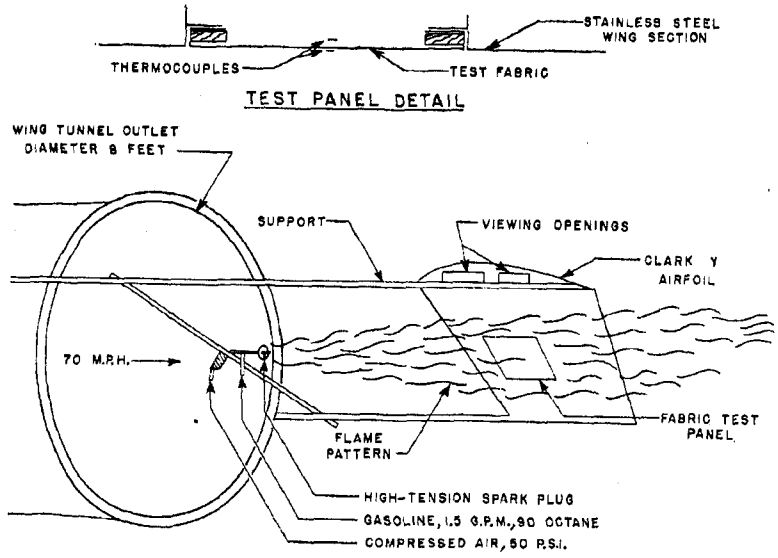

Figure 2. Apparatus for Wind-Tunnel Burning Tests of Fire-Retardant Coatings for Doped Fabric

tegration of the fabric was sudden and complete. At the same time the illumination inside the airfoil suddenly increased. In Figure 3 prints of successive frames of the motion picture record show the fabric destruction between the first and second frames. Temperatures were recorded at points immediately outside and inside the fabric by thermocouples and quick-acting recording pyrometers.

Fifteen experimental fire-retardant coating systems were tested in the wind tunnel. In each system one, two, three, and four coats of fire-retardant material were applied to a fabric previously doped with a standard Navy six-coat doping scheme, consisting of cellulose acetate butyrate dope and applied in accordance with Navy Aeronautical Specification SR-70c. The selection of the materials for this test was based on their performance in the laboratory moving-air burning tests. Panels were prepared several months in advance, so that the effects of solvent retention were negligible. Table II gives the formulations of these fire-retardant coats.

Panels without fire-retardant coatings were also tested to provide a basis for comparison. This latter group included panels coated with Navy-specification cellulose nitrate dope and cellulose acetate butyrate dope, respectively. The number of coats of these two comparison systems was kept constant at six, equivalent to a coating weight of about 4.5 ounces per square yard. Although the char time in the moving-air burning test increases with increase in the weight of cellulose acetate butyrate dope added, this increase is not nearly so great per unit weight of cellulose acetate butyrate dope as it is per unit weight of fire-retardant lacquer. Most of the fire-retardant lacquers tested in the wind tunnel gave char times in the moving-air burning test of 10 seconds or greater for two coats (4 ounces per square yard) of fire-retardant coating added to a six-coat (4.5 ounces per square yard) cellulose acetate butyrate substrate. To achieve a char time of 10 seconds with the addition of cellulose acetate butyrate dope only, it is necessary to add 15 ounces per square yard to a doped fabric already coated with 4.5 ounces of

TABLE II. COMPOSITIONS AND PROPERTIES OF FIRE-RETARDANT COATINGS TESTED IN WIND-TUNNEL FIRE TESTS AT INDIANAPOLIS

Wind-Tunnel Test Coating No.	1	2	3	4	5	6	7	8	9	10	11	12	15	16	17
Natl. Bur. Standards Formula No.	120	121a	255	469	251	470	471	96	484	472	451	450	540	556	558
NONVOLATILE COMPOSITION[a]															
Film base															
Vinylite VYHH	..	..	..	26	..	..	..	..	..	..	..	..	..	..	..
Parlon 125	26	26	26	..	..	..	..	..	..	..	..	..	..	..	..
Parlon R	..	..	..	..	26	26	..	..	..	..	..	..	..	..	..
Parlon X	..	..	..	..	..	..	26	..	..	27	30	30	30	30	26
Dow X-124	..	..	..	..	..	..	..	26	..	..	..	..	..	..	..
Resin 256-27	..	..	..	..	..	..	..	..	48	..	..	..	..	..	..
Amercoat 1138	..	..	40	..	..	..	..	..	..	..	..	..	..	..	..
Mathieson rubber 153b	..	..	..	..	..	..	..	..	..	..	..	..	..	8	..
Polydichlorostyrene	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10
Plasticizer															
Rezyl 36-5	26	26	26	26	13	13	14	26	..	27	14	14	14	14	14
Aroclor 1254	..	..	..	..	..	..	..	..	..	..	..	..	..	8	..
Dibutyl phthalate	4	..	4	..	6.5	..	10	4	..	..	8	8	..	..	10
Dioctyl phthalate	..	..	..	..	..	..	..	..	..	..	..	..	16	..	..
Dow No. 6	..	4	..	4	6.5	..	..	..	..	6	..	..	..	..	..
Hexachloroethane	..	..	..	..	..	..	..	..	12	..	..	..	..	..	..
Diphenyl phthalate	..	..	..	..	..	6.5	..	4	..	..	..	..	..	..	..
Tricresyl phosphate	..	..	..	..	..	6.5	..	..	..	..	..	..	..	..	..
Clorafin 42	4	4	4	4	..	..	10	..	..	..	8	8	..	..	..
Pigment															
Antimony oxide	20	20	..	20	24	24	20	20	20	20	..	..	20	20	20
Calcium carbonate	20	20	..	20	24	24	20	20	20	20	..	..	20	20	20
Magnesium ammonium phosphate	..	..	..	..	..	..	..	..	..	..	..	40	..	..	..
Zinc borate	..	..	..	..	..	..	..	..	..	..	40	..	..	..	..
NONVOLATILE COMPOSITION[a] (SOLVENT)															
Methylethyl ketone	60	..	60	60	..	..	..	100	100	..	100	100	100	..	100
Cellosolve acetate	30	..	30	..	..	..	..	..	..	..	..	..	..	..	..
Butyl acetate	10	20	10	40	..	20	..	..	..	..	..	..	..	..	..
Ethyl acetate	..	80	..	..	..	..	..	..	..	..	..	..	..	..	..
Diacetone alcohol	..	..	..	..	50	..	..	..	..	..	..	..	..	..	..
Aromatic petroleum naphtha, Type I	..	..	..	..	..	60	..	..	..	..	..	..	..	..	..
Toluol (Neville Co.)	..	..	..	..	..	..	60	..	..	60	..	..	..	..	..
Toluene	..	..	..	..	..	..	..	..	..	..	..	..	..	100	..
Xylene	..	..	..	..	..	20	40	..	..	40	..	..	..	..	..
Union solvent No. 8	..	..	..	..	50	..	..	..	..	..	..	..	..	..	..
PROPERTIES															
Fabric destruction time (wind tunnel), sec.[b]	8.2	6.4	7.5	8.8	10.2	10.0	8.0	7.8	10.3	9.4	11.8	10.8	10.0	7.6	8.5
Fabric char time (lab, moving air), sec.[b]	12	16	11	9	12	10	10	17	10	..	12	16	..	10	11
Accelerated weathering[c]	P	P	G	VG	G	G	G	P	P	..	G	P	..	G	P
Panel No. in outdoor exposure test	655	656	..	674	..	..	..	621	..	..	..	..	701	..	..

[a] Figures are in per cent of nonvolatiles and volatiles, respectively. The solutions were made up to contain 25% nonvolatiles.

[b] Times are for panels with four fire-retardant coats. Figure 4 gives results of tests with one, two, and three fire-retardant coats.

[c] Code: P = poor, G = good, VG = very good.

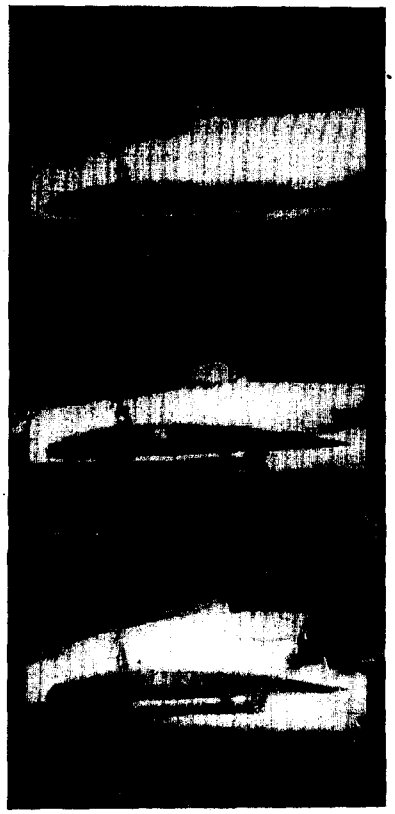

Figure 3. Sample of Motion Picture Record of Wind-Tunnel Burning Tests of Fire-Retardant Coatings

cellulose acetate butyrate dope per square yard.

OTHER PROPERTIES OF COATING SYSTEMS

Not only is it desirable to provide the maximum in fire retardance in a coating, but it is also essential that the coating have a reasonably good life expectancy. The requirements for good airplane fabric coatings are severe. They must be tough enough in all kinds of weather to withstand impacts from pieces of runway gravel as well as normal flying stresses; they must not interfere with the normal fabric tautness; they must be easily applied, show good adhesion to dope, and be smooth.

ACCELERATED WEATHERING TESTS

This accelerated weathering by Method 6021 of Federal Specification L-P-406a was first used as a guide in the selection of coating formulations. The specimen is exposed to cycles of condensed fog, alternated with ultraviolet radiation from a General Electric S-1 sun lamp. This method has proved successful for laboratory evaluation of the resistance of plastics to natural weathering. A standard exposure of 240 hours of this cyclic treatment was used as an initial screening test. A soft alkyd resin, Rezyl 36-5, was found to be particularly effective as a plasticizing resin and superior to the other resins tested in imparting resistance to weathering. Most of the coatings were therefore built around this resin. Test films approximately 10 mils thick were examined with and without pigments, both as free films and as coatings applied to doped fabrics. To be a candidate for outdoor exposure, the test film was required to show sufficient flexibility after the 240 hours of accelerated weathering to permit a 180° fold at room temperature without cracking. The fold was made by hand, with no attempt to control the radius of fold.

OUTDOOR WEATHERING TESTS

Fire-retardant coatings selected for outdoor exposure were applied as topcoats over panels of doped fabric. Tables III to VI show the compositions and properties of the coating systems tested by outdoor exposure. The solutions were made up to contain 25% nonvolatiles. (All fabrics were coated with 10% by weight of a mixture of 3 parts of boric acid and 7 parts of borax before doping.) Two coats were applied, the total coating weight added being approximately 4 ounces per square yard. The test panels were exposed continuously in Washington on outdoor racks facing south at an angle of 45°. Periodic tautness measurements and impact tests were made according to the procedures described by Kline and Reinhart (*3*).

TABLE III. VINYL AND VINYLIDENE CHLORIDE FIRE-RETARDANT COATINGS TESTED IN WASHINGTON

N.B.S. Panel No.	624	625	674	732	733	761	621	697	671	730	731	760
N.B.S. Formula No.	62	62	469	549	550	562	96	96	96	547	548	561
Dope Pigmentation[a]	Al	W	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
NONVOLATILE COMPOSITION, PER CENT BY WEIGHT												
Film base												
Vinylite VYHH	27.2	27.2	26	25.9	25.9	26	...	...	...	...	...	...
Dow resin X-124	...	...	...	...	...	...	26.2	26.2	26.2	25.9	25.9	26
Plasticizer												
Rezyl 36-5	27.2	27.2	26	14	14	14	26.2	26.2	26.2	13.9	13.9	14
Diphenyl phthalate	2.7	2.7	...	...	...	...	3.9	3.9	3.9	10	10	10
Dow No. 6	2.7	2.7	4	19.9	19.9	20	...	...	...	...	...	...
Clorafin 42	20.1	20.1	...	...	...	...	...	...	...	...	...	...
Dibutyl phthalate	...	...	...	...	...	...	3.9	3.9	3.9	10	10	10
Pigment												
Calcium carbonate	20.1	20.1	20	10	10	10	19.9	19.9	19.9	10	10	10
Antimony oxide	...	...	20	29.9	29.9	30	19.9	19.9	19.9	29.9	29.9	30
Stabilizer												
Phenyl salicylate	...	...	4	...	...	...	...	...	...	...	...	...
Urea	...	...	...	0.3	...	...	...	...	...	0.3	...	...
Basic lead carbonate	...	...	...	...	0.3	...	...	...	...	...	0.3	...
VOLATILE COMPOSITION (SOLVENT), PER CENT BY WEIGHT												
Methyl ethyl ketone	60	60	100	60	60	60	100	100	100	100	100	100
Butyl acetate	40	40	...	40	40	40	...	...	...	...	...	...
PROPERTIES												
Fabric char time (moving-air test), sec.	7	7	9	9	12	...	17	17	17	8	9	...
Burning characteristics[b]	A, B, E	A, B, E	A, B, E	A, B, E	A, B, E	...	A, B, E	A, B, E	A, B, E	A, B, E	A, B, E	...
Outdoor weathering												
Initial tautness, mils	106	113	68	81	84	80	106	86	100	96	93	98
Tautness range, mils	73/131	69/139	60/98	63/125	60/127	68/123	71/142	68/S[d]	82/133	69/137	61/137	75/140
Time to first brittle failure, mo.	10	8	4	9	9	5	10	14	2	...	...	6
Total exposure, mo.	11	11	5	11	11	7	31	21	5	17	17	14
Condition of panel[c]	B, D	C, D	F	G, D	B, D	B, D	A, D	A, D	D	A, D	A, D	A, D

[a] Code: Al = aluminum, W = white.
[b] Code: A = afterglow, B = blistering, E = self-extinguishing.
[c] Code: A = exposure test continuing, B = poor adhesion of topcoat to dope substrate, C = erosion of topcoat, D = tautness poor in warm weather, F = experimental hot-application dope substrate, G = poor adhesion of dope to fabric.
[d] S = slack.

TABLE IV. CHLORINATED RUBBER FIRE-RETARDANT COATINGS TESTED IN WASHINGTON

N.B.S. Panel No.	583	584	585	586	587	588	592	593	594	622	623	626	627	655	656	669	726	727
N.B.S. Formula No.	1	2	3	46	50	60	83	84	78	88	88	80	80	120	121	534	543	544
Dope Pigmentation[a]	G	G	G	G	G	G	G	G	G	Al	W	Al	W	Al	Al[a]	Al	Al	Al
NONVOLATILE COMPOSITION, PER CENT BY WEIGHT																		
Film base																		
Parlon 125	42.9	42.9	42.9	38.2	38.2	40.0	26.1	26.1	27.2	27.2	27.2	26.1	26.1	26.2	26.0	26.0	25.7	25.7
Amecco paint	...	...	...	...	...	...	...	...	...	...	...	40.0[d]	40.0[d]	...	...	...	...	...
Amercoat 1138	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	40.0[d]	...	...
Plasticizer																		
Rezyl 36-5	...	...	...	38.2	38.2	40.0	26.1	26.1	27.2	27.2	27.2	26.1	26.1	26.2	26.0	26.0	14.0	14.0
Dibutyl phthalate	7.1	7.1	7.1	5.7	...	...	3.9	...	...	...	...	...	...	3.9	...	4.0	...	...
Diphenyl phthalate	...	...	...	5.7	5.7	4.0	3.9	3.9	2.7	2.7	2.7	3.9	3.9	...	...	4.0	...	...
Triphenyl phosphate	21.4	21.4	21.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Dow No. 6	...	...	...	...	...	4.0	...	...	2.7	2.7	2.7	...	...	...	4.0	...	10.0	10.0
Clorafin 42	...	...	...	...	...	...	...	...	...	20.1	20.1	...	...	...	4.0	...	10.0	10.0
Chlorowax	...	...	14.3	...	...	6.0	...	...	20.1	...	...	...	...	...	...	...	...	...
Flexol 3GH	...	...	...	...	5.7	...	...	3.9	...	...	...	3.9	3.9	3.9	...	...	...	...
Pigment																		
Zinc borate	28.6	...	...	12.2	...	...	40.0	...	...	...	...	...	...	...	...	...	...	...
Calcium carbonate	...	...	14.3	...	...	6.0	...	...	20.1	20.1	20.1	...	...	19.9	20.0	...	10.0	10.0
Magnesium ammonium phosphate	...	28.6	...	...	12.2	...	...	40.0	...	...	...	...	...	...	...	...	...	...
Antimony oxide	...	...	...	...	...	...	...	...	...	...	...	...	...	19.9	20.0	...	30.0	30.0
Stabilizer																		
Urea	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0.3	...
Basic lead carbonate	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0.3
VOLATILE COMPOSITION (SOLVENT), PER CENT BY WEIGHT																		
Cellosolve acetate	...	...	...	...	...	...	...	...	...	...	...	...	...	20.0	...	30.0	...	...
Ethyl acetate	30.0	30.0	30.0	...	...	...	...	...	...	...	...	...	...	...	80.0	...	60.0	60.0
Butyl acetate	20.0	20.0	20.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	20.0	20.0	10.0	40.0	40.0
Methyl ethyl ketone	50.0	50.0	50.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	...	60.0	...	...
PROPERTIES																		
Fabric char time (moving-air test), sec.	9	7	7	10	8	6	11	...	5	8	...	11	...	12	16	...	14	11
Burning characteristics[b]	A, B	A, B	A, B, E	A, B	B, E	A, B, E	A, B, E	...	A, B, E	A, B, E	...	A, B, E	...	A, B, E	A, B, E	...	B, E	B, E
Outdoor weathering																		
Initial tautness, mils	85	70	80	121	100	100	97	91	81	108	115	102	6	80	85	90	94	86
Tautness range, mils	82/148	68/124	68/117	100/141	99/124	94/123	71/115	68/121	65/103	80/141	67/135	72/126	69/139	58/120	67/116	69/S[e]	68/145	64/127
Time to first brittle failure, mo.	15	...	4	4	4	4	2	12	2	10	10	...	8	6	3	4	...	...
Total exposure, mo.	15	19	9	9	9	9	7	16	7	20	11	11	11	7	7	17	18	18
Condition of panel[c]	...	C	...	B, D	...	...	...	C	...	...	C, D	C, D	D	D	D	...	A, D	A, D

[a] Code: Al = aluminum, G = gray, W = white.
[b] Code: A = afterglow, B = blistering, E = self-extinguishing.
[c] Code: A = exposure test continuing, B = poor adhesion of topcoat to dope substrate, C = erosion of topcoat, D = tautness poor in warm weather.
[d] Pigment content included in film base figure.
[e] S = slack.

The tautness readings shown in the tables represent the deflection in thousandths of an inch produced at the center of a doped fabric test panel by a concentrated load of one pound. Therefore, low readings mean good tautness. A value of 100 is taken as the boundary between satisfactory and unsatisfactory tautness. The tendency to poor tautness which results from the nontautening fire-retardant coatings can possibly be neutralized in part by a hot application dope, which gives a high degree of tautness, as the substrate. Thus, the tautness of the composite system might be made equivalent to that of fabric doped with standard cellulose acetate butyrate. However, the hot dope systems require further development to correct poor flexibility before they will be satisfactory.

Although the boric acid–borax treatment does act as an effective fire retardant for fabric, there was evidence that the adhesion of cellulose acetate butyrate dope to fabric was lower in panels containing boric acid and borax.

Few of the coatings tested in this program are as durable or as flexible as the cellulose acetate butyrate dope which is taken as a standard for comparison. The formulas which showed relatively early failure on impact (brittle failure)—i.e., in less than six months—are not recommended for further consideration. However, the coating systems to be described should be considered for further development by interested lacquer manufacturers.

VINYL AND VINYLIDENE CHLORIDE RESINS COATINGS (TABLE III). Half of the Vinylite VYHH coatings developed poor adhesion to dope upon exposure. Panel 625 had white pigment in the substrate dope and showed evidence of erosion. Panel 674 was removed because of impact failure after short exposure.

Stabilizers, such as urea and basic lead carbonate, were effective in prolonging the coating life as may be seen by comparing panel 761, without stabilizer, with panels 732 and 733, containing stabilizers.

The coatings using the vinylidene chloride–acrylonitrile copolymer (Dow resin X-124) as film-forming base show favorable properties, in general, both from the point of view of fire retardancy and of weathering. The superior performance of panels 730 and 731 in comparison with panel 760 demonstrates the effectiveness of urea and basic lead carbonate as stabilizers. The use of equal parts of calcium carbonate and antimony

oxide as pigment in formula 96 appears to be a factor in the marked superiority in fire resistance as compared with coatings from formulas 547 and 548, in which a larger proportion of antimony oxide was used. This variable needs further exploration.

CHLORINATED RUBBER COATINGS (TABLE IV). The four chlorinated rubber coatings which gave best results in the outdoor weathering tests are formulas 2, 84, 543, and 544. However, the erosion of formulas 2 and 84, incident to the use of water-soluble magnesium ammonium phosphate in the pigment, may have been responsible for the failure to show brittleness simply because of the reduction of coating thickness. Formulas 543 and 544 had superior fire retardancy, as compared with formula 2, with respect both to self-extinguishing and to afterglow. Another promising coating is formula 534, prepared by adding chlorinated rubber to an aluminum-pigmented vinyl chloride acetate lacquer (Amercoat 1138). Preliminary accelerated weathering tests of Amercoat 1138 over fabric doped with cellulose acetate butyrate were unfavorable. However, use of the mixture gave good results both in accelerated and natural weathering, except for a single, early brittle failure.

TABLE V. CHLORINATED NEOPRENE FIRE-RETARDANT COATINGS TESTED IN WASHINGTON

N.B.S. Panel No.	628	629	630	631	672	673	698	728	729
N.B.S. Formula No.	100	100	97	97	536	252	250	545	546
Dope Pigmentation[a]	Al	W	Al	W	Al	Al	Al	Al	Al
NONVOLATILE COMPOSITION, PER CENT BY WEIGHT									
Film base									
Parlon R	26.0	26.0	26.0	26.0	16.0	30.0	30.0	25.8	25.8
Amercoat 1138	..	..	..	..	..	40.0[d]	..	..	..
Plasticizer									
Rezyl 36-5	26.0	26.0	26.0	26.0	60.0	15.0	15.0	13.9	13.9
Diphenyl phthalate	4.0	4.0	4.0	4.0	..	7.5	7.5	..	..
Dibutyl phthalate	..	..	4.0	4.0	3.0	..	..	10.0	10.0
Tricresyl phosphate	..	..	..	..	..	7.5	..	..	..
Dow No. 6	..	..	..	..	..	..	7.5	..	..
Aroclor 1254	..	..	..	..	3.0	..	..	10.0	10.0
Flexol 3GH	4.0	4.0	..	..	..	..	..	..	..
Pigment									
Calcium carbonate	..	..	20.0	20.0	9.0	..	20.0	10.0	10.0
Magnesium ammonium phosphate	40.0	40.0	..	..	..	..	..	..	..
Antimony oxide	..	..	20.0	20.0	9.0	..	20.0	30.0	30.0
Stabilizer									
Urea	..	..	..	..	..	..	..	0.3	..
Basic lead carbonate	..	..	..	..	..	..	..	..	0.3
VOLATILE COMPOSITION (SOLVENT), PER CENT BY WEIGHT									
Methyl ethyl ketone	34.0	34.0	34.0	34.0	..	..	..	100	100
Toluene	33.0	33.0	33.0	33.0	..	..	..	..	..
Trichloroethylene	33.0	33.0	33.0	33.0	..	..	..	..	..
Diacetone alcohol	..	..	..	..	50.0	..	50.0	..	..
Union solvent No. 8	..	..	..	..	50.0	..	50.0	..	..
Aromatic petroleum naphtha, Type I	..	..	..	..	..	60.0	..	..	..
Xylene	..	..	..	..	..	20.0	..	..	..
Butyl acetate	..	..	..	..	..	20.0	..	..	..
PROPERTIES									
Fabric char time (moving-air test), sec.	14	14	23	23	..	9	12	10	12
Burning characteristics[b]	A, B, E	A, B, E	A, B, E	A, B, E	..	A, B, E	A, B, E	B, E	A, B, E
Outdoor weathering									
Initial tautness, mils	86	90	94	93	71	68	87	97	92
Tautness range, mils	74/121	74/116	74/121	58/104	61/102	65/109	59/115	67/135	64/133
Time to first brittle failure, mo.	..	8	..	10	2	2	13	9	..
Total exposure, mo.	11	11	11	11	5	5	16	18	18
Condition of panel[c]	C, E	C	C, E	C, E	F	F	G	A, E	A, E

[a] Code: Al = aluminum, W = white.
[b] Code: A = afterglow, B = blistering, E = self-extinguishing.
[c] Code: A = exposure test continuing, C = erosion of topcoat, E = fine cracking of topcoat, F = experimental hot-application dope substrate, G = poor adhesion of dope to fabric.
[d] Pigment content included in film base figure.

CHLORINATED NEOPRENE COATINGS (TABLE V). Formulas 545 and 546, containing urea and basic lead carbonate as stabilizers, show best resistance to weathering. Formula 97 (panels 630 and 631) appeared better in the laboratory burning tests. Formula 470, almost like formula 97, was excellent in the wind-tunnel fire tests (wind-tunnel test coating 6 of Table II and Figure 4). The use of equal parts of calcium carbonate and antimony oxide plus one of the stabilizers would probably yield a coating having the improved weathering resistance of formulas 545 and 546 and the fire retardancy of formula 97. The chlorinated neoprene formulas gave the smoothest coatings of any of the materials tested.

CHLORINATED POLYISOPRENE COATINGS (TABLE VI). Formulas 466 and 540 gave the best all-round performance in the outdoor weathering test, although both panels became slack on one occasion during a prolonged wet spell. The mixed base coating, using chlorinated polyisoprene (Parlon X) and Amercoat 1138, showed an early brittle failure but otherwise gave good results.

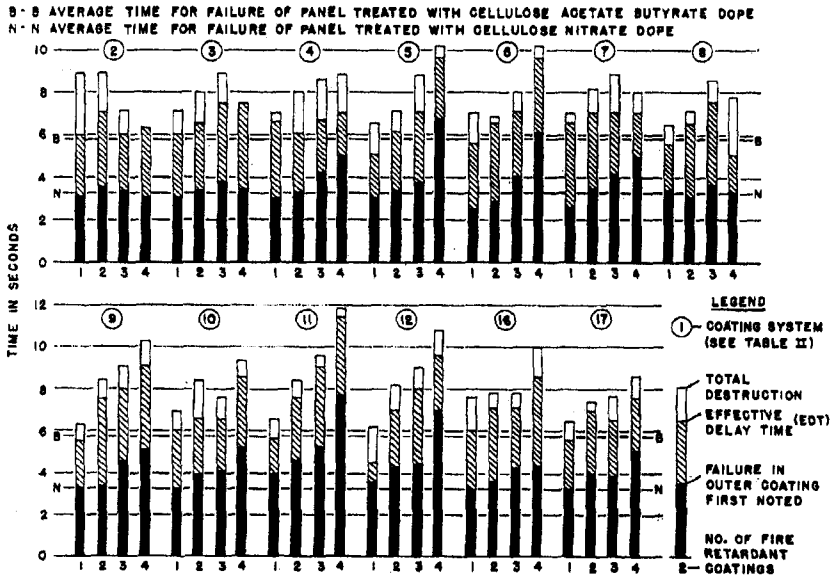

Figure 4. Burning Times of Doped Fabrics Covered with Fire-Retardant Coatings in Wind-Tunnel Test

RESULTS OF WIND-TUNNEL TESTS

Table II and Figure 4 present the results of the wind-tunnel burning tests at Indianapolis. Figure 5 shows the appearance, after the tests, of panels which had been doped with cellulose nitrate and cellulose acetate butyrate, with and without fire-retardant coatings on the dope surfaces. It is noteworthy that the panel doped with cellulose nitrate and coated

TABLE VI. CHLORINATED POLYISOPRENE AND MISCELLANEOUS FIRE-RETARDANT COATINGS TESTED IN WASHINGTON

N.B.S. Panel No.	670	699	700	701	724	725	720	721	708	709	722	723
N.B.S. Formula No.	535	466	467	540	451	451	[a]	[a]	Pyropex		Skylac	
Dope Pigmentation[b]	Al	Al	Al	Al	W	G	W	W	W	W	B	B
NONVOLATILE COMPOSITION, PER CENT BY WEIGHT												
Film base												
Parlon X	26.0	30.0	30.0	30.0	30.0	30.0	Standard Navy system		Pyropex system		Skylac system	
Amercoat 1138	40.0[f]	...	...	...	...	...						
Plasticizer												
Rezyl 36-5	14.0	14.0	14.0	14.0	14.0	14.0						
Dibutyl phthalate	10.0	16.0	...	...	8.0	8.0						
Aroclor 1254	10.0	...	16.0	...	...	...						
Flexol DOP	...	...	...	16.0	...	...						
Clorafin 42	...	...	...	...	8.0	8.0						
Pigment												
Zinc borate	...	...	...	...	40.0	40.0						
Calcium carbonate	...	20.0	20.0	20.0	...	...						
Antimony oxide	...	20.0	20.0	20.0	...	...						
VOLATILE COMPOSITION (SOLVENT), PER CENT BY WEIGHT												
Methyl ethyl ketone	...	100	100	100	100	100						
Toluc	60.0	...	...	...	...	...						
Xylene	40.0	...	...	...	...	...						
PROPERTIES												
Fabric char time (moving-air test), sec.	...	...	...	...	12	9	5[g]	5	5	5	5[g]	5
Burning characteristics[c]	...	...	...	...	A, B, E	B, E	...	...	...	...	...	...
Outdoor weathering												
Initial tautness, mils	113	97	84	93	109	110	74	81	59	59	80	85
Tautness range, mils	74/139	66/S[d]	66/108	70/S[d]	67/141	57/143	71/103	70/100	53/S[d]	53/S[d]	65/116	60/120
Time to first brittle failure, mo.	4	14	2	13	4	9	7	9	...	...	10	...
Total exposure, mo.	18	21	15	21	11	11	11	11	19	19	19	19
Condition of panel[e]	D	A	...	A	B, D	B, D	...	G	A	A	A, D	A, D

[a] No fire-retardant coating.
[b] Code: Al = aluminum, B = blue-gray, G = gray, W = white.
[c] Code: A = afterglow, B = blistering, E = self-extinguishing.
[d] S = slack.
[e] Code: A = exposure test continuing, B = poor adhesion of topcoat, D = tautness poor in warm weather, G = poor adhesion of dope to fabric.
[f] Pigment content included in film base figure.
[g] No boric acid-borax mixture on fabric.

with a fire-retardant coating was destroyed more quickly and extensively than the panel coated with cellulose acetate butyrate dope only.

Coating failure in this investigation is taken as the time required for the coating to be destroyed to such an extent that it is partially swept away by the windstream. During this interval the temperature on the outside of the panel rises considerably more rapidly than that on the inside. When the coating is completely swept away, the inside temperature rises sharply. The elapsed time until the temperature rises on the inside is a partial measure of the fire-retardant effectiveness of the coating. The coating, in blistering, apparently acts as a blanket and flame deflector. The sharp temperature rise occurs when this blanket is removed so that the doped surface is again in contact with the flame. Figure 6 shows the time-temperature relations. The times shown by the bar graphs in Figure 4 for total destruction, as evidenced by fire break-through, are taken from the motion picture records; these records are considered to be somewhat more reliable than the data either from the manually operated stop watch, or from the time-temperature charts. The values of time given in Figure 4 and Table II are the original data for single panels.

In general, increased fire protection was given by increasing the number of fire-retardant coats, with the exception of coating system 2 for which no explanation is apparent. The zone of incident flame from the burning gasoline was sharply confined to half the panel area. This provided a criterion of extent of propagation of the fire to areas not in contact with the original flame. The burnt areas of the fire-resistant panels were confined to those regions immediately in contact with the flame. This was true also of the panels coated with cellulose acetate butyrate dope only, but not of the panels coated with cellulose nitrate dope. In some instances the cellulose nitrate panels were completely consumed.

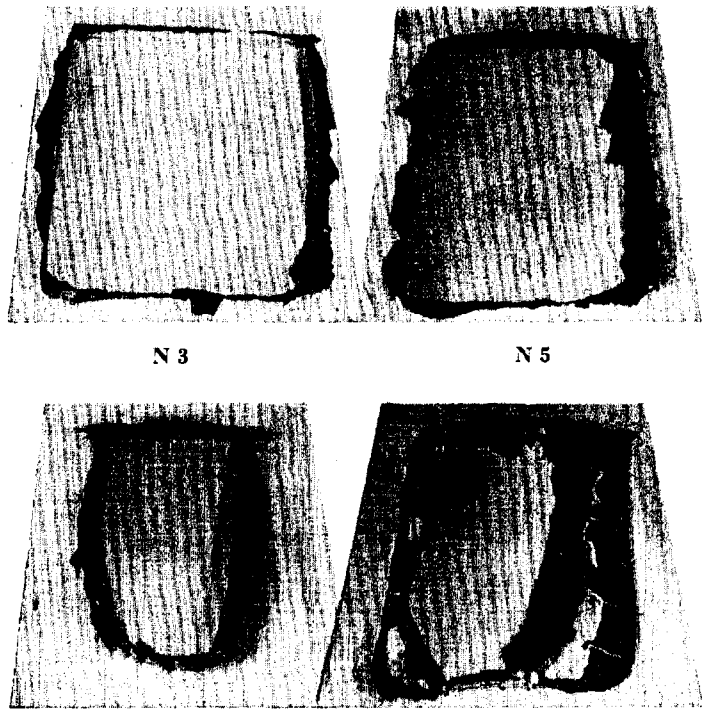

Figure 5. Appearance of Panels after Simulated Power-Plant Fire Tests in Wind Tunnel

N 3. Cellulose nitrate dope; destruction time, 2 seconds
N 5. Cellulose nitrate dope plus four coats of fire-retardant coating 11 (Table II); destruction time, 4 seconds
B 6. Cellulose acetate butyrate dope; destruction time, 6 seconds
11 D. Cellulose acetate butyrate dope plus four coats of fire-retardant coating 11 (Table II); destruction time, 12 seconds

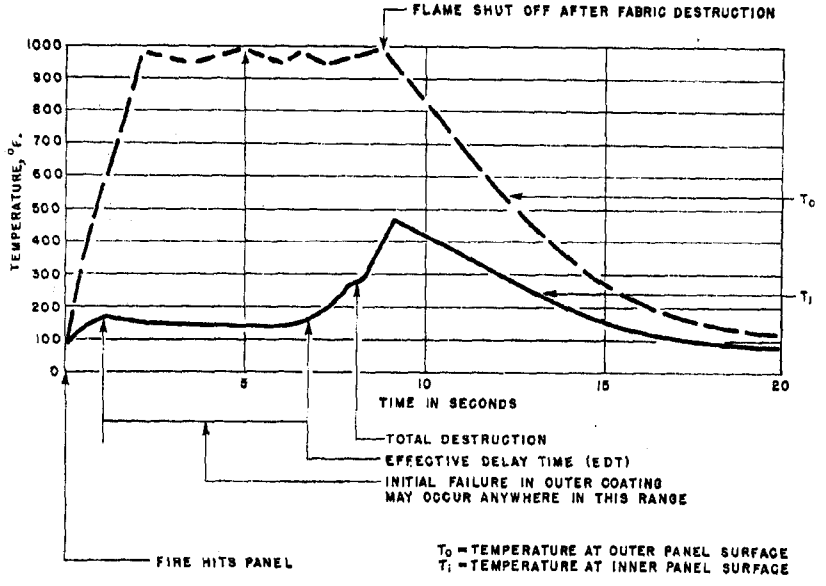

Figure 6. Typical Time-Temperature Record of a Test Panel during Wind-Tunnel Burning Test

Under the conditions of fire, the cellulose acetate butyrate melted before it ignited. The coating melted also with chlorinated neoprene systems 5 and 6.

An almost universal property of the fire-retardant systems was the development of blisters by the generation of gases incident to the pyrolysis of the fire-retardant materials. The only exception was system 11 which did not exhibit the blisters characteristic of the other systems but seemed to be one big bubble; zinc borate was the pigment used in this system, which showed the best fire-retardant properties of any tested. From the point of view of keeping the coating in place for as long a period as possible, the formation of small blisters is better than the formation of one large bubble, which might easily be blown loose by the wind stream.

During the progress of the tests, it became apparent that an important limiting factor in protection was the brittleness of the burnt outer coating. Some improvement can be expected if the outer coating is designed to have greater mechanical strength after burning, so that it will not be so easily blown away by the wind stream. There appear to be no systematic differences in the results obtained with the several plasticizers investigated.

Afterglow, although a significant property in the still-air burning tests because of reignition, was not important in either the laboratory moving-air or wind-tunnel burning test. However, in the wind-tunnel tests large sections of the aluminized coating on a panel, doped with cellulose acetate butyrate containing aluminum pigment, were ignited and blown away as a shower of burning particles downstream. This could conceivably constitute a reignition hazard.

Since coating systems examined in the wind-tunnel tests were selected from those showing up best in the laboratory tests, the differences in fire-retardant effectiveness among the systems is relatively small. However, there is no doubt that these coatings are substantially superior in fire retardancy to a cellulose acetate butyrate system alone. Their superiority over cellulose nitrate systems is marked.

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Correction Factor for Latent Heat

Method for Obtaining Haggenmacher Correction Factor without Use of Critical Values

R. R. DREISBACH

The Dow Chemical Company, Midland, Mich.

A method has been developed for calculating the Haggenmacher correction factor for latent heats by means of a modified Antoine equation for vapor densities and the law of rectilinear diameters for liquid densities. This method eliminates the necessity of having critical values, and uses instead the boiling point and liquid density.

HAGGENMACHER (*3, 4, 5, 6*) has developed a number of formulas from an equation of state for saturated liquids and the Clapeyron-Clausius equation by means of which the latent heat of vaporization and external work of vaporization can be accurately calculated.

The three Haggenmacher equations pertinent to this article are:

$$V_g - V_l = \frac{RT}{MP}\sqrt{1 - \frac{T_c^3 P}{P_c T^3}} \qquad (1)$$

$$\Delta H = \frac{RT^2}{MP}\frac{dp}{dt}\sqrt{1 - \frac{T_c^3 P}{P_c T^3}} \qquad (2)$$

$$-\Delta A = P(V_g - V_l) = \frac{RT}{M}\sqrt{1 - \frac{T_c^3 P}{P_c T^3}} \qquad (3)$$