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A STUDY OF HOUSE PAINT PROPERTIES

by
John Harris

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A study of house paint properties

What is the real role of moisture in blistering?

By JOHN HARRIS
Research officer, Organic Materials Section, National Research Council, Division of Building Research

● Failures of exterior house paints by peeling and blistering constitute a serious problem that needs explanation in terms of some of the basic properties of the paints and their relation to conditions that may prevail in service. At the same time a knowledge of these properties and the methods of determining them would be useful in evaluating house paints in order to select those most likely to provide good performance.

It has been the aim in this work to choose and study both separately and in relation to each other those properties that are believed to play an important role in determining the durability of a paint applied to an exterior wood surface. These are adhesion, tensile strength and elongation, water absorption, swelling, and permeability not only in the original state of a freshly applied coating but also after a period of curing equivalent to natural weathering. The relation between these properties has been examined and the behaviour of the paints applied entirely by themselves as well as in systems consisting of a priming coat differing from the top coats, in both cases subjected to some of the conditions that may prevail during the use of a paint. White house paints, which are also the basis of many of the tint and light colours, have been chosen since they form the most important class of house paints and one in which difficulty frequently occurs.

Experimental paints representative of existing and potential house paints as well as a series varying in pigment volume were prepared. Formulation details are shown in **Table I.** A number of actual commercial house paints were also obtained for examination in a similar way.

A series of four paints with increasing pigment volume were based on the conventional oil house paint formula. They were prepared with pigment volumes up to 70% to provide information on film properties ranging beyond the critical pigment volume concentration. These were not considered practical paints, but were used to show the effect of decreasing water absorption and increasing permeability.

Measurements and tests were carried out on free films and on panels. Free films were used for the measurement of tensile properties, water absorption and permeability. They were prepared by a special procedure previously developed, which provided a ready supply of large quantities of free film.

Painted wooden panels were used for blister box tests. It was assumed that these tests would provide moisture conditions similar to those that might arise at critical times on the siding of a house. The results of the tests were compared with the individual properties as measured.

Tensile properties were measured by means of a Gardner Tensile Tester modified to provide mechanical magnification for the lower 20% portion of the scale. Strips of paint 1 by 3.75 in. and about 1.5 mils in thickness were used. These were evaluated for elongation and breaking strength after laboratory aging of 2 weeks and irradiation exposures of 5, 10 and 15 days in a fadeometer. Several groups of commercial paints were tested at a later date and because of unavailability of a fadeometer an XW type was used. These measurements were difficult because of the fragile nature of the film, especially after irradiation. Great care had to be exercised in the preparation of the strips and in their handling. Even with care many specimens were lost by tearing and cracking, and there was high variability in the measurements so that an adequate number of strips had to be provided. Ten strips were prepared for each paint and each treatment and this usually provided for at least seven determinations except in the case of some of the very brittle films.

Laboratory aging for these specimens and for the other tests was done under controlled temperature and

First of two parts

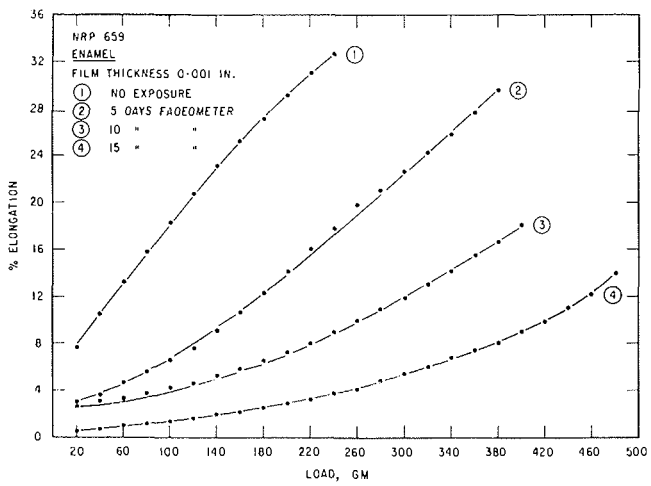

FIG. 1. Tensile tests on an alkyd paint.

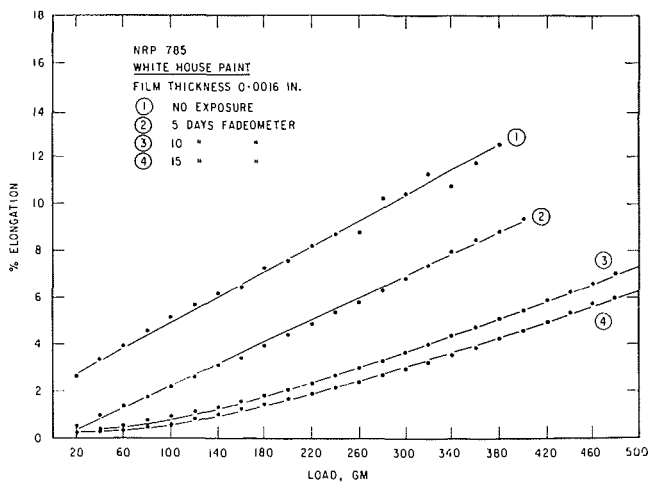

FIG. 2. Tensile tests on alkyd—oil paint.

humidity conditions at 22 deg C and 50% relative humidity.

For water absorption measurements, free films were cut to 2 by 2 in. for weight gain measurements and 2 by 0.3 in. for dimensional change measurements. Dimensional change specimens were cut in both the direction of drawdown of the film and across it. The strips were immersed in boiled distilled water in trays at 22 deg C for periods of ½, 1, 2, 4, 8, 16, 28, 48, 72, 96, 120, 144 and 168 hours (1 week); at the end of each of these intervals a separate strip was removed for measurement. Weight gain films were blotted with tissue and weighed quickly. Dimensional change strips were measured while still wet on an accurate steel rule under a low power microscope to 1/100 in. A number of paint films were also tested in this way after a period of arc irradiation.

Permeability determinations were made on free films using ASTM specification E 96-53T, procedure A carried out at a temperature of 22 deg C and relative humidity gradient from 50% outside to 0% inside the cup. Permeances were obtained as perms and converted to permeability, i.e., perms per mil film thickness.

Blister box conditions were maintained with a temperature difference of approximately 15 deg C (55 deg C on the humid side and 40 deg C on the painted exterior side of the panel) to give rapid saturation of panels and development of effects. The temperatures were recorded and adjusted when there was a need to do so. Dimensions of the panels and their weights were taken before and at the conclusion of the test. Standard quality red cedar and white pine panels ½ in. thick were used. They were given three coats of paint at approximately 600 sq. ft. per gallon spreading rate for each coat. Experimental paints were applied in three ways: (1) self-primed, (2) with white lead primer and two top coats, and (3) with flat alkyd primer and two top coats. The ends of panels were sealed but the backs were not. After at least two weeks' aging they were subjected to the blister box test. A similar set of panels were irradiated in a weatherometer operated continually with two arcs for 24 hours per day with a relative humidity of 50% for a period of 20 days. This exposure was considered long enough to reduce changes in properties to a low rate and to bring these properties to a condition comparable to that ultimately attained outdoors. No absolute relationship between this irradiation and an equivalent one outdoors has been developed, but previous experience with outdoor exposure led to the belief that this amount of irradiation would approximate a spring to fall outdoor exposure in the Ottawa area.

Panels from the series of commercial paints were prepared using their own primers, but otherwise treated in the same way.

Results of Tensile Properties Meas-

TABLE I

EXPERIMENTAL PAINTS

Paint	Pigmentation	Vehicle	Per Cent PVC
NRP 566	TiO_2-BCWL-ZnO-Mg Sil	Raw and Bodied Linseed Oil	33.6
NRP 659	TiO_2	Medium Oil Length Alkyd	19.6
NRP 785	TiO_2-Mg Sil	Extra Long Oil Alkyd	29.7
NRP 786	TiO_2-PbZn-Mg Sil	Extra Long Oil Alkyd: Linseed Oil 1:1	35.4
NRP 787	TiO_2-ZnO-Mg Sil	Extra Long Oil Alkyd: Linseed Oil 1:1	34.5
NRP 788	TiO_2-Mica-Mg Sil	Isophthalic Alkyd	31.4
NRP 842	BCWL	Linseed Oil	31.0
NRP 843	BCWL-ZnO-Mg Sil	Linseed Oil	29.1
NRP 828	TiO_2-BCWL-ZnO-Mg Sil	Raw Linseed Oil Bodied Linseed Oil	39.8
NRP 829	TiO_2-BCWL-ZnO-Mg Sil	Raw Linseed Oil Bodied Linseed Oil	49.8
NRP 830	TiO_2-BCWL-ZnO-Mg Sil	Raw Linseed Oil Bodied Linseed Oil	59.9
NRP 831	TiO_2-BCWL-ZnO-Mg Sil	Raw Linseed Oil Bodied Linseed Oil	69.9

TABLE II (a)

PER CENT ELONGATION AT BREAK OF PAINT FILMS

Paint	Film Thickness mil	Irradiation, Days, Fadeometer						
		0	5	10	15	20	25	79
566	1.0	9.9	3.9	1.7	***	***		
659	1.0	32.8	25.6	22.8	15.1	17.7	17.1	13.8
785	1.6	11.7	9.6	7.6	8.1			
786	1.6	5.8	0.8	***	***			
787	1.8	7.4	2.1	1.2	0.9		***	
788	1.6	7.4	3.0	6.4				
842	1.6	18.0	10.4	7.8	4.1		3.0**	
843	1.7	10.3	2.8	0.9	***		***	

** Based on two strips—remaining 7 strips lost due to brittleness

*** No determination possible due to brittleness of paint film strips.

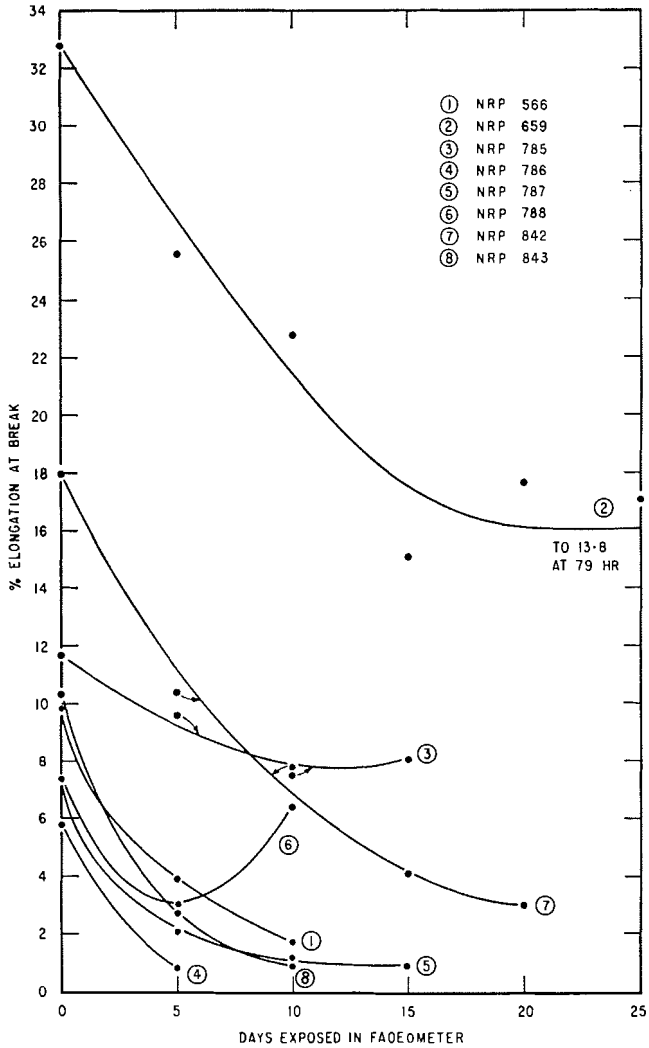

FIG. 3. Elongation at break with varying exposure.

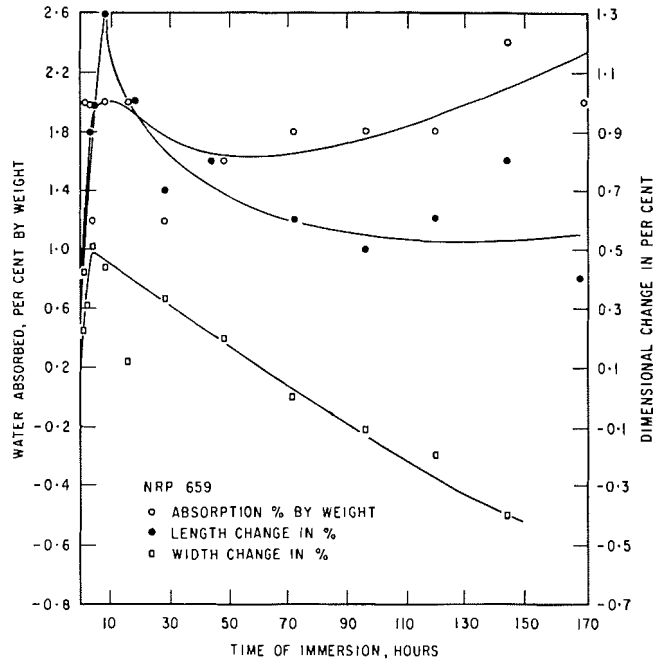

FIG. 5. Water absorption of free films—alkyd paint.

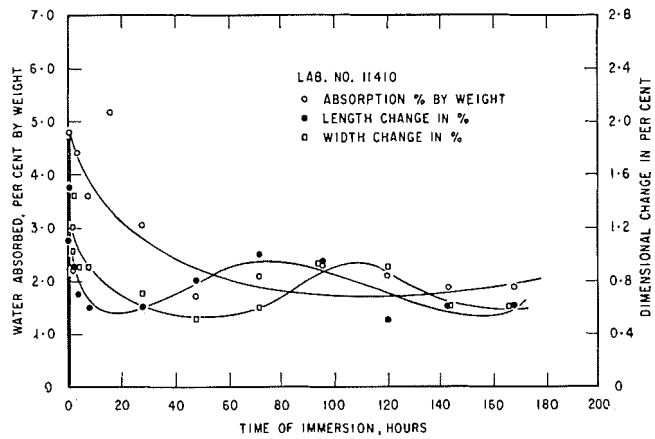

FIG. 6. Water absorption of free films—latex paint.

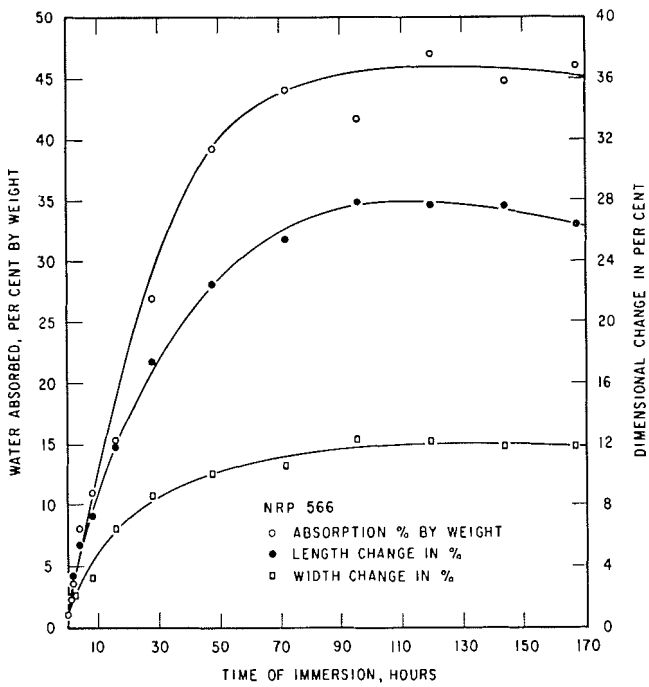

FIG. 4. Water absorption of free films—oil paint.

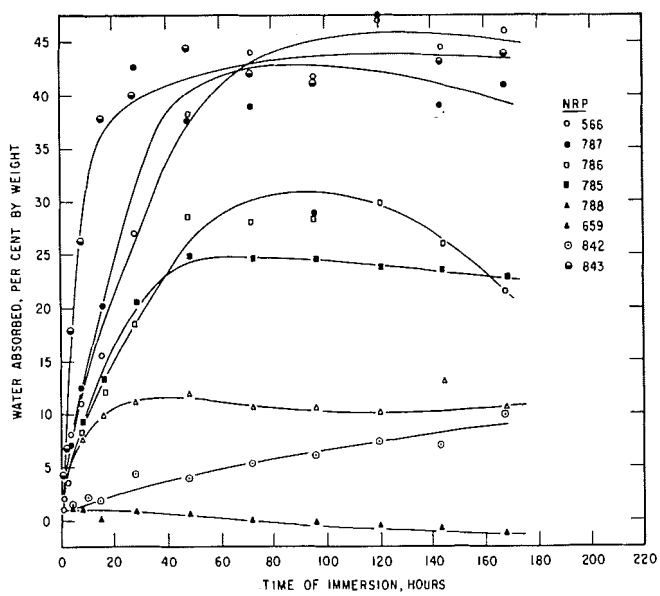

FIG. 7. Water absorption of free films.

urements—Initial elongation and the way this changed with irradiation varied considerably for the experimental paints made up for these studies. Two graphs **(Figs. 1 and 2)** illustrate the elongation versus loading curves for two of the paints. The change in elongation at failure with increasing periods of irradiation is shown for eight of the experimental paints in Fig. 3. Elongations at break and breaking strengths are given for eight experimental paints in **Tables II(a) and III.** Extensibilities of groups of three types of commercial paints before and after irradiation are shown in **Table II(b).** It may be noted that the paints formulated in this experimental work with only alkyd resins as a vehicle (NRP 659, NRP 785) or alkyd resin as the major portion of the vehicle (NRP 788) had higher original extensibility and higher extensibility after irradiation. Part of the superior extensibility of NRP 659 may be attributed to the higher proportion of vehicle as this paint was formulated to a pigment volume concentration of 19.6%. NRP 785 and NRP 788 had pigment volumes almost the same as those of NRP No. 566, 786, 787, 842 and 843, but showed better tensile properties. This would appear to demonstrate a basic difference between the synthetic alkyd vehicle and conventional oil vehicles, or those that contain a high proportion of oil, with respect to level of extensibility and degree of retention of extensibility. White lead linseed oil paint, showing high extensibility initially, did not lose this as rapidly as the mixed pigment-linseed oil paint although it continued to depreciate. Alkyd paints 659 and 785 levelled off in rate of loss of extensibility, and 788 showed an increase in the interval of test. NRP 659 was exposed for seventy-nine 24-hour periods of irradiation in a fadeometer after which time its extensibility was still 14%. Commercial latex paints varied widely. Some showed large values of extensibility and retained a large measure of it after irradiation; others had lower original extensibilities and low values after irradiation.

Breaking strengths generally increased with exposure for all the paints studied, but the changes were not as large proportionately as those for decrease in extensibility.

Results of Water Absorption Measurements—A number of typical water absorption curves are shown in **Figs. 4, 5** and **6.** These indicate water uptake and the corresponding changes in dimensions for a conventional oil-based house paint, an alkyd paint and a latex paint at various stages of immersion up to one week. Values for eight experimental paints are plotted in **Figs. 7, 8** and **9,** showing weight gain and increase in length and width.

Water absorption and its relation to formulation are shown in **Tables IV, V, VI, and VII** (page 40). Water absorption varied from low values of the order of 1% increase in weight to high values of the order of 50 to 70%. These extremes correspond

TABLE II (b)

Extensibilities of various types of commercial paints including those used in blister box experiments

		Per Cent Elongation at Break		
Lab. No.	Type	Original	5 days* National Weatherometer	5 days** Fadeometer
11411	Oil	6.8	4.9	
11416		10.6	5.0	
11436		11.4	7.4	
11443		10.1	7.2	5.8
11425		9.4	4.4	
11421		13.3	8.2	
11420		12.7	3.0	2.8
11413		13.5	4.7	
11418		24.6	21.5	
11414	Alkyd	26.4	32.5	
11488		38.2	22.7	
11489		36.2	18.8	
11410	Latex	7.8	4.4	
11423		38.4	38.2	
11435		45.2	17.3	7.7
11442		76.6	56.1	
11452		19.0	8.5	
11453		19.2	8.3	
11458		11.8	4.9	

* Approximately 18-hour exposure to arc per day
** 24-hour exposure to arc each day

TABLE III

BREAKING STRENGTH OF PAINT FILMS
Grams load per inch width

		Irradiation, Days, Fadeometer						
Paint	Film Thickness mil	0	5	10	15	20	25	79
566	1.0	156	250	284	***	***		
659	1.0	242	326	465	496	536	494	528
785	1.6	278	375	485	556			
786	1.6	397	513	***	***			
787	1.8	373	437	391	414	***		
788	1.6	350	264	437				
842	1.6	244	333	313	476	390	**	
843	1.7	338	386	468	***			

** Based on two strips—remaining 7 strips lost due to brittleness
*** No determination possible due to brittleness of paint film strips

TABLE IV

WATER ABSORPTION CHARACTERISTICS OF EXPERIMENTAL PAINTS

Paint	Pigment	Vehicle	Per Cent Pigment Volume Concentration	Water Absorbed* Per Cent by Weight	Length Increase* Per Cent	Width Increase* Per Cent
NRP 659	TiO_2	Alkyd	19.6	2.0	1.3	1.0
NRP 785	TiO_2-Mg Sil	Alkyd	29.7	24.8	5.9	11.9
NRP 786	Ti-Pb-Zn-Mg Sil	Oil-Alkyd	35.4	29.7	8.8	15.2
NRP 787	Ti-Zn-Mg Sil	Oil-Alkyd	34.5	47.8	9.7	18.6
NRP 788	TiO_2-Mg Sil	Isophthalic Alkyd	31.4	12.9	1.8	3.0
NRP 566	Ti-Pb-Zn-Mg Sil	Oil	33.6	47.0	12.1	26.7
NRP 828	Ti-Pb-Zn-Mg Sil	Oil	39.8	30.0	9.7	19.6
NRP 829	Ti-Pb-Zn-Mg Sil	Oil	49.8	17.7	4.5	11.4
NRP 830	Ti-Pb-Zn-Mg Sil	Oil	59.9	20.0	2.3	5.8
NRP 831	Ti-Pb-Zn-Mg Sil	Oil	69.9	18.8	0.9	1.6
NRP 842	BCWL	Oil	31.0	9.7	7.0	8.1
NRP 843	BCWL-ZnO-Mg Sil	Oil	29.1	48.2	23.6	30.5

* Maximum values attained on film aged 14 days at 22° C, 50 per cent relative humidity.
Length increase was measured in the direction of film drawdown.
Width increase at right angles to this direction.

to alkyd and latex paints that have low absorption and oil-based paints that have high absorptions. Intermediate values were obtained from admixtures of alkyd and oil vehicles.

Dimensional changes parallel the varying amounts of water absorbed. They were not equal in all directions, as may be seen from differences between length-wise and width-wise swelling. Swelling was greater at right angles to the direction in which the paint was applied. Dimensional increases varied from a few per cent to 20 to 40% for oil paints.

High water absorption by weight, coupled with low dimensional change would appear to arise from absorption into voids between pigment particles (paints 830 and 831, **Table IV).**

The series of paints (paints 566, 828, 829, 820, 831, **Table IV)** formulated with gradually increasing pigment volume showed decreasing water absorption with increasing pigment volume to the point of the critical pigment volume concentration when porosity developed as shown by the permeability results given later in **Table IX.** Thereafter, the weight of water absorbed did not continue to decrease but there were appreciable dimensional changes which decreased in direct relation to the amount of vehicle present.

Aging by irradiation brought about a decrease in water absorption as shown in **Table VIII** (page 41). This was generally quite large for oil paints,

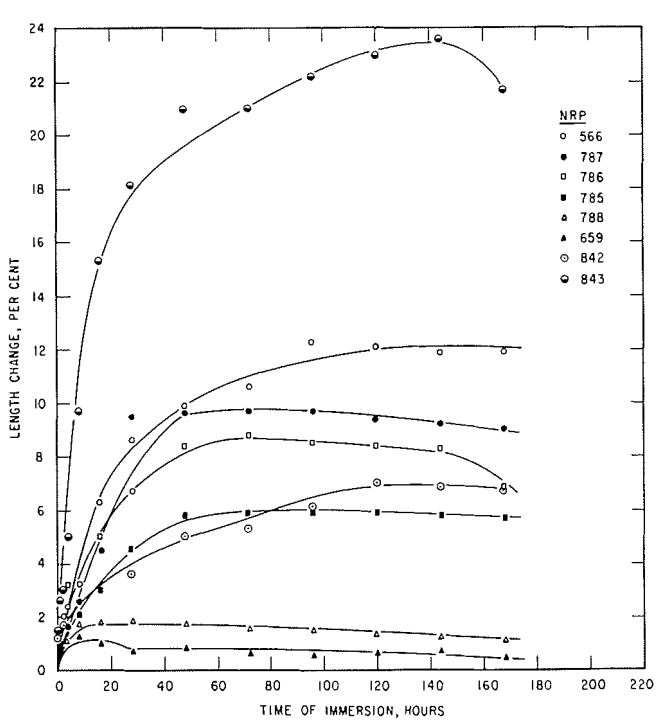

FIG. 8. Water absorption of free films.

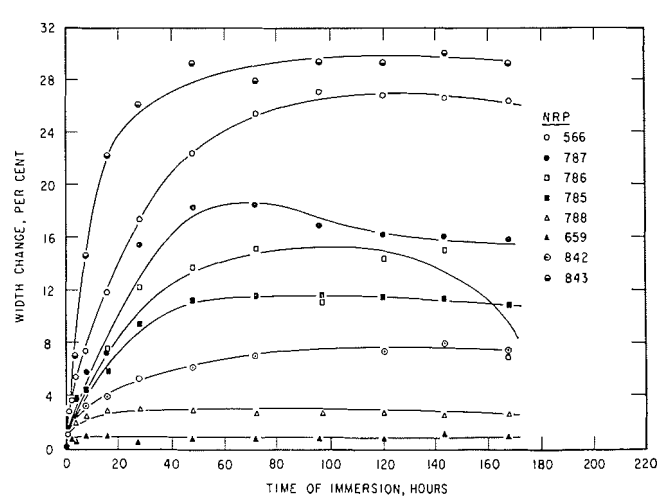

FIG. 9. Water absorption of free films.

which in one case dropped from 62 to 21% for weight of water absorbed and from 22 to 25% to 6 and 9% for the dimensional changes. In other cases changes were not as large or occurred more slowly.

Water absorbed depended therefore on the type of vehicle used, on pigmentation, pigment volume and the extent to which the paint was irradiated.

It is interesting to note that of nine

TABLE V

BEHAVIOUR OF COMMERCIAL PAINTS

Oil-Based Top Coat over Oil-Based Primers: Blister Box and Water Absorption

Lab No.		Not Irradiated	Irradiated 480 hr Double Arc	Water* Absorption Per Cent by Weight	Length* Change Per Cent Original	Width* Change Per Cent Original
Primer	Top Coat					
11411	11411	Blisters	Cracks	44.9 (96)**	19.1	22.8
11415	11416	Blisters	Cracks	61.8 (72)	25.7	36.8
11431	11436	Blisters	Cracks	66.3 (72)	23.8	35.4
11445	11443	Blisters	Cracks	58.8 (120)	15.9	43.9
11424	11425	Blisters	Cracks	60.7 (28)	21.6	34.4
11422	11421	Blisters	Blisters Cracks	68.3 (48)	22.7	31.4
11419	11420	Blisters	Cracks	66.5 (72)	31.0	40.0
11413	11413	Blisters	Slight Cracking	48.5 (96)	20.0	22.8
11419	11418	Slight Blistering	Slight Blistering No Cracks	61.9 (144)	21.9	24.8

* Maximum values attained for top coat films aged 14 days at 22° C, 50 per cent relative humidity
** Figure in bracket denotes time required to attain stated value

TABLE VI

BEHAVIOUR OF COMMERCIAL AND EXPERIMENTAL PAINTS

Alkyd Top Coats With and Without Oil Primers: Blister Box and Water Absorption

Lab No.		Not Irradiated	Irradiated 480 hr Double Arc	Water* Absorption Per Cent by Weight	Length* Change Per Cent Original	Width* Change Per Cent Original
Primer	Top Coat					
11414	11414	Tough film No deleterious effects	Tough film No deleterious effects	8.9 (72)**	3.8	4.0
11415***	11414	Few blisters Tough film No other deleterious effects	Very few blisters, Tough film No other deleterious effects	8.9	3.8	4.0
11445***	11444	A few blisters Tough film	Tough film No deleterious effects	1.7 (2)	2.2 (16)	1.9
NRP 659	NRP 659	Very tough No effects	Very tough No effects	1.1 (4)	1.3	1.0
NRP 785	NRP 785	Tough No effects	Tough No effects	24.8 (48)	5.9	11.9
NRP 494***	NRP 659	Blisters	Tough No effects	1.1	1.3	1.0
NRP 494***	NRP 659	Blisters	Tough No effects	1.1	1.3	1.0

* Maximum values attained for top coat films aged 14 days at 22°C, 50 per cent relative humidity
** Figure in bracket denotes time required to attain stated value
*** Oil-based primers

TABLE VII

BEHAVIOUR OF COMMERCIAL PAINTS

Latex Paints over Oil-Based Primers: Blister Box and Water Absorption

Lab No.		Not Irradiated	Irradiated 480 hr Double Arc	Water* Absorption Per Cent by Weight	Length* Change Per Cent Original	Width* Change Per Cent Original
Primer	Top Coat					
11409	11410	Slight softening	No deleterious effects	5.2 (16)**	1.5 (1)*	1.4
11432	11435	No deleterious effects	No deleterious effects	3.7 (72)	3.0 (½)	3.2
11445	11442	Slight softening	No deleterious effects	0.9 (4)	2.7 (1)	2.7
11422	11423	Slight softening	No deleterious effects	1.6 (½)	2.0	2.6

* Maximum value attained for top coat films aged 14 days at 22°C and 50 per cent relative humidity
** Figure in bracket denotes time required to attain stated value

TABLE VIII

CHANGE IN WATER ABSORPTION EFFECTS WITH IRRADIATION

240 Hours Double-Arc Exposure

		Max. Water Absorption Per Cent by Weight		Max. Length Change Per Cent		Max. Width Change Per Cent	
Paint	Type	Original	Exposed	Original	Exposed	Original	Exposed
11417	Blister-proof	19.0	9.0	6.7	2.9	10.4	6.0
11418	Oil	61.9	21.1	21.9	6.1	24.8	9.0
11420	Oil	66.5	74.7	31.0	13.0	40.0	23.7
11421	Oil	68.3	62.7	22.7	14.7	31.4	21.0
NRP 785	Alkyd	24.8	1.8	5.9	1.9	11.9	2.4
NRP 787	Oil-Alkyd	47.8	20.1	9.7	4.0	18.6	7.7
NRP 788	Alkyd-Oil	12.9	4.5	1.8	1.0	3.0	1.5
NRP 659	Alkyd	1.1	2.2	1.3	2.5	1.0	5.0

commercial house paints examined all showed high water absorption and correspondingly high dimensional change. There were large differences in expansion measured in the direction of drawdown of film in comparison with measurements at right angles to the drawdown.

It is also interesting to note that a white lead paint which is based entirely on an oil vehicle had remarkably low water absorption in comparison with other oil paints formulated with mixed pigments.

A study of house paint properties

What is the real role of moisture in blistering?

(In the first article in these series, Mr. Harris set out his study approach. Here he reaches conclusions—Ed.)

By JOHN HARRIS
Research officer, Organic Materials Section, National Research Council, Division of Building Research

Results of Permeability Measurements — Experimental paints for which the pigment volumes have been calculated and commercial solvent-based house paints presumed normal in pigment volume showed very little variation in permeability until the region of critical pigment volume was approached. At this point there was a very large increase in permeability. Permeability values below critical pigment volume were of the order of 2 to 5 perms per mil of paint under conditions of test. Three of the latex paints examined had permeabilities of an intermediate value. High permeabilities associated with critical pigment volumes (about 45%) were usually 40 perms and more. Permeabilities are shown in **Tables IX and X.**

Results of Blister Box Tests—Blister box tests were most useful in revealing the behaviour of various experimental paints on wood in relation to individual properties. Results are given in **Table XI** for the experimental paints and **Tables V, VI, and VIII** for the commercial paints. The following observations were made:

1. Paints with relatively large water absorption values (25% absorption or more by weight at 22 deg C) blistered when used alone on wood (white pine and red cedar). Blistering has always been associated with the presence of free water in excess of the fibre saturation point of the wood to which the paint film is attached. Oil-based paints had high water absorption values and showed concomitant blistering even, in some cases, when extensively modified with synthetic resins. Paints with absorption values lower than about 25% by weight had, when used by themselves, no blistering tendencies even under conditions considered extreme with regard to wetness of the wood.

2. Paints aged by irradiation diminished in blistering tendency, if this was originally present, so that in most cases the tendency eventually disappeared, probably due to decrease in capacity for absorbing water. Cracking often developed in paints that showed large loss of extensibility with irradiation. Oil-based paints followed this pattern of blistering in the early stages and cracking in later stages. Occasionally both prevailed at the same time. Alkyd type paints used and those based on latex did not show blistering originally and did not suffer any deleterious effects such as cracking after the aging period used in these experiments.

3. Blistering occurred when white lead in oil was used as the primer, even with paints considered blister resistant. No blistering occurred when a flat alkyd primer with low water absorption characteristics was used. Paints that inherently tend to blister resisted blistering when applied over the flat alkyd primer. A conventional house paint, which showed a marked propensity to blister by itself and over a white lead primer, did not suffer this effect when used over a flat alkyd primer, perhaps because the primer is a barrier to liquid water. The flat alkyd primer used, however, did not change the cracking behaviour of top coats.

4. Adhesion to wood did not appear to be the only or even the most important factor in the initial development of paint defects under moisture conditions. It varied and was often adequate or quite good even to wet wood and generally improved with

TABLE IX
Dry cup permeability of experimental paints

Paint	% Pigment Volume	Permeability*
NRP 659	19.6	3.6
NRP 785	29.7	3.2
NRP 786	35.4	2.9
NRP 787	34.5	3.8
NRP 788	31.4	2.5
NRP 842	31.0	5.2
NRP 843	29.1	4.1
NRP 566	33.6	3.6
NRP 828	39.8	4.0
NRP 829	49.8	40.2
NRP 830	59.9	251.7
NRP 831	69.9	430.9

* Grains per sq ft per hr for 1 mm Hg vapour pressure difference per mil thickness

TABLE X
Dry cup permeability of commercial paints

Number	Type	Permeability*
11411	Oil	4.8
11413	Oil	5.0
11416	Oil	5.1
11418	Oil	1.7
11420	Oil	3.5
11421	Oil	5.4
11425	Oil	4.6
11436	Oil	3.8
11443	Oil	4.0
11414	Alkyd	5.6
11434	Alkyd	4.3
11444	Alkyd	2.4
11423	Latex	13.7
11435	Latex	18.4
11442	Latex	27.6
11410	Latex	3.3
11412	Peel-proof	242.8
11417	Blister-proof	1.1
11433	Valvet Flat	3.6

* Grains per sq ft per hr for 1 mm Hg vapour pressure difference per mil thickness

TABLE XI

BLISTER BOX EFFECTS

Experimental Paints over Various Primers* Before and After Irradiation**

		Self-Primed		White Lead - Oil Primer		Flat Alkyd Primer	
Paint	Effect	Not Irradiated	Irradiated	Not Irradiated	Irradiated	Not Irradiated	Irradiated
NRP 566	Blisters	Dense	Slight	Dense	Dense	None	None
	Cracks	None	Dense	None	Dense	None	Dense
	Adhesion	Poor	Very good	Poor	Fair+	Fair	Very good
NRP 659	Blisters	None	None	Medium+	None	None	None
	Cracks	None	None	None	None	None	None
	Adhesion	Good	Good	Poor	Good	Poor	Very good
NRP 785	Blisters	None	None	Dense	None	None	None
	Cracks	None	None	None	None	None	None
	Adhesion	Good	Very good	Poor	Very good	Good	Very good
NRP 786	Blisters	Medium	None	Dense	Dense	Few	None
	Cracks	None	Dense	None	Dense	None	Dense
	Adhesion	Good	Very good	Poor	Good	Fair	Very good
NRP 787	Blisters	Dense	None	Very dense	Dense	Very few	None
	Cracks	None	Dense	None	Dense	None	Dense
	Adhesion	Good+	Very good	Poor	Very good	Fair+	Very good
NRP 788	Blisters	None	None	Few	None	Very few	None
	Cracks	None	None	None	Few	None	None (red cedar) Dense (white pine)
	Adhesion	Good+	Good+	Poor	Good	Very good	Very good
NRP 842	Blisters	None	None	—	—	—	—
	Cracks	None	Dense	—	—	—	—
	Adhesion	Good	Very good	—	—	—	—
NRP 843	Blisters	Dense	Dense	—	—	—	—
	Cracks	None	Dense	—	—	—	—
	Adhesion	Very poor	Very good	—	—	—	—

*Two top coats over one prime coat at 600 sq ft/gal
**480 hr double arc (twin arc weatherometer) exposure

irradiation. Determinations of adhesion by testing blisters with a knife showed that weak regions in a paint coating system were often not at the wood interface but within one of the layers of paint, usually that which had the greatest water absorption.

The incidence of weak regions in various layers may be deduced from the results in **Table XII.**

Discussion of Tensile Properties— Tensile properties of house paints must be considered in relation to the wood surface to which they are applied. Measurements of expansion in the dimensions of panels used in the blister box tests (conditioned at 23 deg C and 50% relative humidity) show crossgrain expansions with increased moisture content up to fibre saturation point to average 4.1% of original for northern white pine (41 measurements; range 2.53 to 6.16%) and 1.5% for western red cedar (30 measurements; range 0.36 to 2.92%). These extensions exceed the extensibilities of three of the experimental oil-based paints after irradiation, when their extensibilities in free film form had decreased to about one. The three paints showed cracking on panels subjected to blister box conditions. Nine commercial paints showed similar cracking after irradiation; their tensile properties were similar to those of the three experimental oil-based paints. Another commercial paint showing high extensibility even after irradiation resisted cracking on the blister box. Unaged oil paints have enough capacity for elongating to accommodate the expansion of the wood when it becomes wet. Aging under the influence of irradiation rapidly depletes this accommodation to extension.

The paints examined in this work that were based on alkyd vehicles, both of laboratory manufacture and from commercial sources, produced tough elastic films which showed no tendency to crack under the experimental conditions employed. They possessed extensibilities of sufficient magnitude even after irradiation to withstand the dimensional changes of swelling wood. Commercial latex house paints also showed the ability to withstand similar strains.

Cracking phenomena observed in the course of these experiments do not alone explain paint peeling since no peeling was observed even after long exposures (running to 11 months) to accelerated weathering.

Cracking similar to that obtained on panels in laboratory tests commonly occurs in areas of wood readily susceptible to water absorption, i.e.,

exposed end grain of boards, window ledges and trim. In such cases the cracking is closely spaced and delamination is slow. Flaking eventually results. In contrast, peeling usually develops quite rapidly over much larger areas. It is believed that cracking occurs when the strains imposed by dimensional changes in the substrate exceed those the film is capable of withstanding; the adhesion of the paint may be quite good, as has been observed on cracked paints from blister box tests.

The flaking of paint between stress cracks may be a slow gradual process of swelling and shrinking at the edges of small islands of cracked paint and a working inward. Peeling appears to result from a general destruction of adhesion over a relatively large area. None of the paints studied in this program showed such loss of adhesion during the length of time used for the tests. Although adhesion under some circumstances was low, complete loss was not observed. Factors causing complete loss of adhesion must still be determined.

Elastic and plastic properties, together or separately, are needed to accommodate the dimensional changes of wood brought about by changes in moisture content in service. Stresses may be relieved by elastic extension or plastic deformation. Paints to be used on wood should be selected from those that will have adequate extensibilities throughout their intended life. The simple laboratory measurements of extensibility of paint films are related to the behaviour of the paint on wood and can provide a logical standard of selecting paints for wood to eliminate at least one possible type of failure.

Discussion of Blistering—The effect of water transmitted through the wood substrates to the back of paint coatings was studied. Such water conditions are said to be the cause of many paint failures. Only one defect has ever been noted in the laboratory, however, that is attributable to the moisture condition created by water transmitted through the back of painted wood, and that is blistering. Rather severe laboratory conditions involving substantial temperature differences across the board have been required to produce blistering. Isothermal conditions do not appear to favour the accumulation of water beneath paint films, a prerequisite for blistering. It has been necessary to establish a temperature of 55 deg C on the back of a panel and 40 deg C on the painted face in order to produce conditions that encourage blistering in less than 24 hours. When the backs of the panels were subjected to a temperature of 36 deg C leading to a temperature at the painted surface of 24 deg C, blistering development was greatly reduced in rate, size and density, and a number of days were required before blisters appeared. For blisters to form in the laboratory either large temperature differences must exist if short periods are involved or relatively long periods of lower temperature differences must prevail. Such conditions are not likely to exist in the case of house paints on wood.

TABLE XII

Observations of regions of easiest separation in paint coatings applied to wood and exposed on blister box

			Region of Easiest Separation Incidence	
Type of Primer	**Type of Top Coat**	**Region**	**Not Irradiated**	**Irradiated**
Oil	Oil	Primer	20	21
Oil	Alkyd	Primer	5	7
		Lower layer of primer	2	—
		At wood	8	2
		Not evident	2	2
Oil	Latex	Primer	6	6
		Lower layer of primer	2	
		At wood	2	
Alkyd	Oil	Primer	3	
		At wood		1
		Not evident		3
Alkyd	Alkyd	Primer	1	1
		At wood	2	—
		Not evident	2	2
None	Oil	Primer	6	
		Lower layer of primer		2
		At wood		1
None	Alkyd	Lower layer of first coat	4	1
		At wood	2	1
		Not evident		1
Vinyl (solution)	Vinyl (solution)	At wood	2	2

The description "not evident" means good adhesion and cohesion throughout so that any assessment of location of weakest stratum is not possible by the simple subjective procedures used.

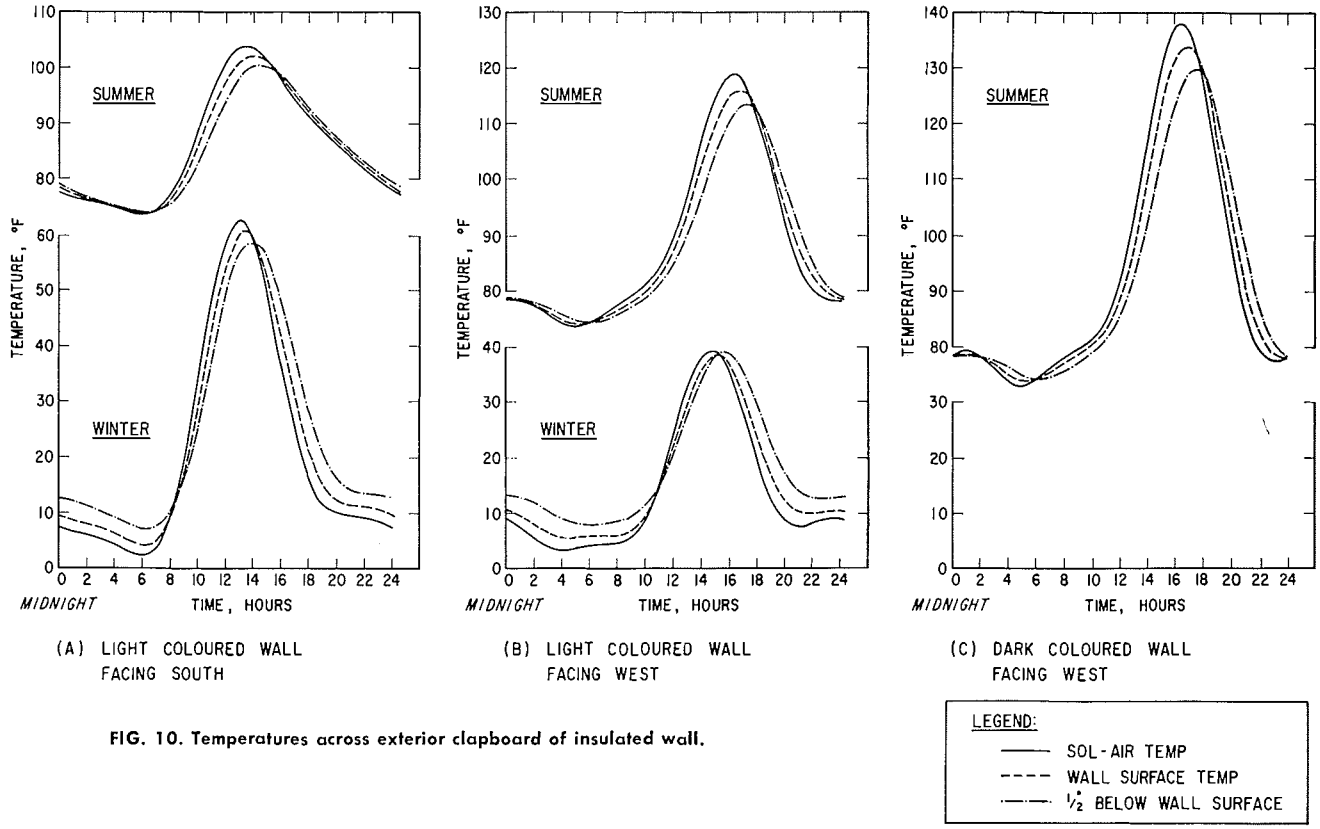

FIG. 10. Temperatures across exterior clapboard of insulated wall.

Calculations have been made of temperature differences that may exist between the back and front of a ½-in. board used as siding on an insulated wall of a heated house with light and dark coloured paint for summer and winter conditions and western and southern exposures **(see Fig. 10).** These have shown that only small temperature differences of a few degrees occur over a ½-in. siding thickness and that those differences considered most favourable to water accumulation occur mainly during the winter and are intermittent. Part of the time the differences are in the reverse direction to that required for water to move to the outside surface. It is believed that similar temperature differences but under steady conditions in laboratory tests would not produce blistering, especially since at lower temperatures the water absorbed by the paint is decreased. It has been shown that laboratory blistering is related to the water sensitivity of the paint as revealed by water absorption and swelling tendencies.

It does not appear likely that conditions for the formation of blisters on exterior wooden surfaces would occur except under circumstances that differ markedly from the example (used in these discussions) of the wall considered to follow good normal construction practice. Field observations do not bear out the common belief that blistering of painted siding is extensive. Peeling of paint is prevalent but this appears to be a separate phenomenon not related to blistering.

Discussion of Permeability — Paints that have been formulated in the normal pigment volume range, including the experimental alkyd and oil types and a number of similar commercial latex paints, have not shown marked differences in their values of dry cup permeability. These permeabilities are usually all relatively low, ranging from 2 to 5 perms per mil thickness of film, and have not shown any systematic variation of permeability with the different types of paints investigated **(see Tables IX and X).** These small differences in permeability may be effective in preventing the accumulation of water behind paint films when the transmission of water through wood is low and of the same order of magnitude. This will be the case when small temperature differences prevail. Should conditions arise to increase the rate of water transfer the ability of the paint films to prevent accumulation may be readily exceeded.

A dry cup method has been used for measuring permeability. This method is sometimes used to assess house paints for their efficacy in coping with accumulating moisture in walls of houses to which the paints are applied. It was the purpose to learn what relationships existed between the measurements obtained by the dry cup procedure and the behaviour of paints on wet wood. It appears that there may be a limited use for measurements obtained in this way in interpreting the behaviour of paints on wood, but it should always be kept in mind that the dry cup test conditions are limited to the lower half of the humidity range.

The transmission of water through a material is usually represented by a simple flow equation incorporating a coefficient of permeability. It is known that such a coefficient is itself a function of several variables and may vary widely with temperature, temperature gradient and relative humidity. For many materials permeability increases with relative humidity under isothermal conditions. Wet cup tests commonly show higher permeabilities than do dry cup tests for the same material. There is some evidence that water sensitive materials can show extreme differences. The wet cups sometimes used do not produce the conditions a paint may encounter in use, i.e., involving actual contact with water, temperature dif-

ferences and cycling conditions. A further complication may arise from the combination of the paint and the wood.

It is evident that dry cup measurements should not be used to draw conclusions that are too general about the working permeabilities of paint and that a procedure more closely simulating actual conditions would be useful.

It was found that when experimental conditions that provided a water vapor pressure difference of about 20 mm Hg (back of panel wet 31 deg C, front of panel 28 deg C at about 50% R.H.) the water vapor transmission of paint studied (permeabilities 3-5) was not sufficient to prevent the eventual accumulation of free water.

The accumulation of water may, however, be reduced by markedly increasing permeability through increased pigment content. This was done by progressively raising the pigment volume of a set of paints (NRP 566, 828, 829, 830, 831, **Table I**). Permeability was affected very little until a pigment volume exceeding 40% had been reached and the paint became porous. The permeability increased suddenly (as for NRP 829) and continued to do so markedly.

These paints have permeabilities of a magnitude sufficient to prevent water accumulation even with the large water vapor pressure difference (estimated at 50 mm) created by a temperature difference of 15 deg C (55 to 40 deg C across the panel). The paints formulated to produce these high permeability properties however, lost their desirable tensile properties and were very subject to cracking when the wood to which they were applied absorbed water. It is believed that with conventional paints there is little possibility of increasing permeability without risking brittle paints.

A number of commercial latex paints have dry cup permeabilities in the intermediate range without any sacrifice in tensile properties. There are latex paints, however, whose permeabilities did not exceed those of the conventional oil or alkyd types measured.

Paints having higher than normal permeabilities (2 to 5 perm) were susceptible to stain and resin exudation from the wood.

It does not appear that the improvement in blister resistance of oil and alkyd type paints through adjustment of "breathing" characteristic is a safe practice, although it may be possible with certain kinds of latex.

Since there has been found a dependence of blistering on level of water absorption of all the paints studied, oil, alkyd, and latex, it is considered that greater advantage may be gained by formulating paints in the normal permeability range, choosing vehicles that will provide low water absorption together with good tensile properties. It has been found that the alkyd and latex paints studied have these properties initially and retain them when subjected to accelerated weathering.

Discussion of Adhesion — Observations made on adhesion during the blister box experiments are reported in **Tables XI and XII.** Adhesion, determined by the knife test, was in many cases quite good, and even on those panels where it was relatively poor it was still substantial. In no case studied was there complete separation of paint from the undersurface. Adhesion was often good even on areas between blisters and on wood that was saturated with water.

Adhesion improved when the paints applied to wood were subjected to irradiation in a weatherometer. Since this treatment also reduces the water absorption of the paints, it was thought that there is some relationship between adhesion and water absorption. The point was clarified by closer observation of blisters and regions of easiest separation during the performance of the knife test. Blisters formed in most cases within the paint film rather than at the paint and wood boundary and could occur in various strata, depending probably on their relative water sensitivity.

Probing with a knife also revealed that weak regions in paint coatings on wet panels could vary and could occur in different strata of the paint system and at times at the paint and wood interface **(see Table XII).** It would appear that in many cases the weakest region of a paint system on wood subjected to wetness from the back and possibly from the front is within the paint itself rather than at the surface of the wood. Dissimilarities in paints from either formulation or aging may determine the layer of greatest water sensitivity and consequent softening. It may be within such weak layers that blisters most readily form; and it may be presumed that cohesion and intercoat differences are more relevant to blistering than is adhesion to wood, at least in the early stages of the life of a paint system.

Discussion of Systems—Under study the paints showed a wide range of water absorption, swelling and tensile properties. The dissimilarities may be expected to lead to varying degrees of incompatibilities when the paints are used together in systems. Besides differences in properties because of the use of these different types of paints, differences may arise from the relative aging of the respective layers in a paint system, since they do not all receive the same exposure and do not respond equally to the same treatment. It is probable that even with paints of the same composition incompatibilities arise because of time intervals between applications of coats and the more rapid changes occurring in top layers by weathering. The influence of water with respect to the incompatibilities in a system would be expected to be important. Whether water arises from the back or the front of the paint coats, differential stresses may be produced in the various strata having unequal swelling and shrinking characteristics and differences in blistering tendencies because of differing response to absorbed water.

One example of incompatibility found in the experiments occurred when an alkyd paint was applied over a white lead primer. The alkyd paint showed no blistering when applied directly to wood or over an alkyd primer having similar water absorption properties. When applied over a white lead in oil priming paint with greater water sensitivity, however, the system blistered.

Ideally, it may be presumed that the various coats of a paint system should be selected for such properties as water absorption and tensile properties, not only for the initial period of the life of the coating system but also for the more advanced stages which may be reached at different rates. These properties should also be matched to the wood surface to which they are applied.

Conclusion—A number of properties of conventional and experimental house paints have been studied on free films. These have included water absorption with corresponding dimensional changes, extensibility and breaking strength, and permeability. All but the last were investigated after both normal laboratory aging and a

nominal period of irradiation in a weatherometer as well. The relationship between values obtained for measurement of these various properties of the various paints used and their behaviour on wood subjected to moisture conditions was examined. It was found that for the paints studied:

(1) Laboratory blistering of a paint occurred in direct proportion to its water absorption.

(2) Irradiation in a weatherometer reduced water absorption of free films. Those paints that originally had relatively high water absorption and blistered on wood when subjected to tests improved in blister resistance after irradiation.

(3) Cracking of paints on wood subjected to the expansions produced by wetting of the wood can be related to the extensibility of the paint measured by a simple procedure. Cracking was avoided when extensibility values exceeded the dimensional changes in wood.

(4) Oil- and alkyd-based paints in the normal pigment concentration range and latex paints examined initially possessed sufficient extensibility to avoid cracking on wood. Excessive pigmentation reduced extensibility below critical values for use on wood and cracking occurred when wood expanded with water absorption. Irradiation in a weatherometer reduced extensibility values of free films.

There were marked differences among the types of paints with respect to the rate of loss of extensibility. Oil paints after irradiation were found to reach low levels quickly. Alkyd and latex were found to retain a large measure of extensibility and lose it much more slowly. Oil paints that had been applied to wood and subjected to irradiation were found to be susceptible to cracking when the wood swelled.

(5) No systematic relationship could be found between dry cup permeability and the various types and formulations of paints pigmented in the normal pigment range.

(6) Blistering is not necessarily governed by adhesion. Adhesion to wood is not necessarily destroyed by water. Weaknesses and blisters in the cases studied developed mainly within the paint system rather than at the wood boundary.

(7) No effects were observed in the course of the tests that would explain complete loss of adhesion leading to peeling. Peeling is considered to be a separate phenomenon not necessarily related to blistering and one which may arise from factors or conditions not observed or included in this study.

It is believed that the measurement of water absorption and tensile properties and their changes under the influence of accelerated weathering as carried out in this study can provide useful information for the selection of house paints. It is evident that more knowledge is required on adhesion, and its relationship to these other physical properties.

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