12-1959

The Effect of Ultraviolet Light on the Color of Unbleached Pulps: Literature Survey

David L. Brew
Western Michigan University

THE EFFECT OF ULTRAVIOLET LIGHT ON THE COLOR OF UNBLEACHED PULPS

Literature Survey

By

David L. Brew

December 8, 1959

Submitted to Dr. A. H. Nadelman, Professor of Paper Technology, Western Michigan University as required for Research Problems in Pulp and Paper, Course #570

THE EFFECTS OF ULTRAVIOLET LIGHT ON THE COLOR OF UNBLEACHED PULPS

TABLE OF CONTENTS

THE EFFECTS OF ULTRAVICLET LIGHT ON THE COLOR OF UNBLEACHED PULPS

SUMMARY

A literature survey was prepared which covered the published information on the effects of ultraviolet light on the color of unbleached pulps.

Experiments were conducted with eight types of unbleached pulp which were converted into optical test pads under varying pH conditions, using sulphuric acid and caustic soda as well as alum and sodium aluminate for adjustment of the hydrogen ion concentration. The optical test pads were exposed to ultraviolet irradiation. Thereafter, reflectance measurements were taken, covering the range of visible light.

From the limited number of experiments which were conducted we can conclude that:

1. Unbleached coniferous kraft, unbleached hardwood, sulphite, and unbleached hardwood soda pulps brightened when exposed to ultraviolet light.
2. Unbleached hardwood N.S.S.C.(70% yield), unbleached hardwood N.S.S.C.(78% yield), unbleached coniferous sulphite, unbleached hardwood cold soda, and unbleached hardwood chemi-groundwood pulps yellowed when exposed to ultraviolet light.
3. Adjusting the pH to four with sulphuric acid increased the reflectance of most pulps while adjusting the pH to ten with sodium hydroxide decreased the

reflectance of the pulps. This was observed before irradiation with ultraviolet light.

4. When papermakers' alum was used to adjust the pH of the sheets to four, the reflectance values before irradiation decreased slightly in most cases. There was a larger drop in the reflectance value when the pH of the pulp is adjusted to the pH ten with sodium aluminate.

5. Both means of adjusting the pH to ten, namely sodium hydroxide and sodium aluminate, decreased the initial brightness of the pulp. However, there was little correlation between the effects of the two compounds used to adjust the pulp pH to four, namely sulphuric acid and papermakers' alum.

6. Experimental results showed that none of the compounds used in pH control stabilized consistently the color of unbleached pulp exposed to ultraviolet irradiation.

David L. Brew

David L. Brew

THE EFFECT OF ULTRAVIOLET LIGHT ON THE COLOR OF UNBLEACHED PULPS

Subjectively, a definition of light would be,- the sense impression formed in the eye. This definition would seem to include only that which can be seen. Customarily, however, ultra-violet and infra-red lights are included as a part of light even though they cannot be seen. The distinction between the different types of light radiation is one of convenience, since all represent a single phenomenon. Their differences lie mainly in wave lengths; ultra-violet lies below the limit of the visable spectrum, and above the x-rays.(1) The usually accepted wave lengths for ultra-violet light are from 400 to 300 millimicrons for "near" ultra-violet light, and 300 to 200 millimicrons for "far" ultra-violet light.(2)

THE COLOR OF PULP

Color, as it is defined by Webster, is- "a sensation evoked as a specific response to stimulation of the eye and its attached nervous mechanisms by radiant energy of certain wave lengths and intensities."(3)

The color of pulp is regarded as the spectral reflectivity and is illustrated by a curve of the ratio of reflectance in the range of visable light, with 700 and 400 millimicrons as the upper and lower wave length limits. In more specific terms, color is specified according to the standard observer and colorimetric coordinate system recommended by the International Commission of

Illumination(I.C.I.). However, the appearance of a pulp sample is not completely defined by these specifications. Other variables, such as texture, may influence the pulps appearance.(4)

HOW ULTRA-VIOLET LIGHT AFFECTS UNBLEACHED GROUNDWOOD

It should be noted that the action of light produces two recognized effects: a "yellowing" of the sample, and a "fading".(6) "Yellowing" implies a deeping of the color, while "fading" is a whitening of the color.

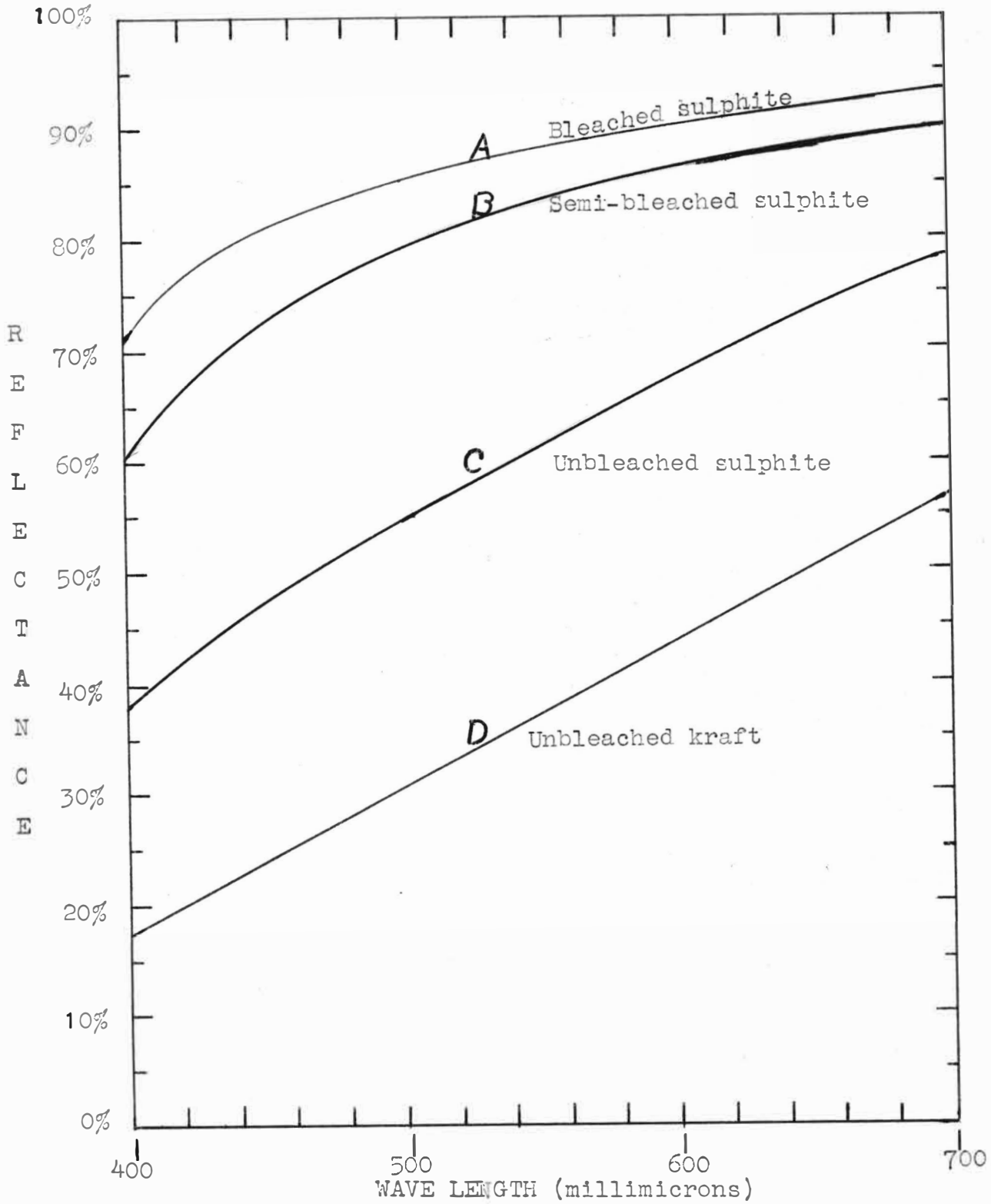
The effect of ultra-violet light on groundwood produces, in general, a yellowing of the pulp. It has been found that irradiation in the far ultra-violet range, 385 to 400 millimicrons, will increase the brightness of groundwood for the first 18 hours, but subsequently the brightness decreases. Lignin and the extractives are believed to cause this yellowing, since both have a high ultra-violet light absorption.(7) There is some dissention on this point, as Forman (8) found the color of native lignin relatively stable to the action of ultra-violet light.

THE VARIATIONS WITH TIME

It is known that the largest drop in brightness, resulting from the pulp being exposed to ultra-violet light, takes place in the first two hours of exposure. After this period, Lewis, Reineck, and Fronmuller (6) found that the drop in brightness is nearly a straight line function of time. Van den Akker, Lewis, Jones, and

SPECTRAL REFLECTIVITY CURVES

Figure 1



Curves A and D--(4)

Curves B and C--(5)

Buchanan reported that the changes in the sheet are strongly nonlinearly related with the time of exposure to the light from a Fade-O-meter.(7)

Graff (9) found that groundwood exposed to the action of ultra-violet light decreased in brightness very rapidly for the first 24 hours, much less for the next 24 hours, and only very slowly for longer periods of time.

THE VARIATIONS WITH HEAT

Another factor which influences the color of the pulp and is difficult to separate from the action of ultra-violet light, is heat.

Launer and Wilson (10) found that temperature does not greatly affect the yellowing of groundwood. This evidence was supported by Lewis, Reineck, and Fronmuller. (6) Nolan, Van den Akker, and Wink (11) found that heat in the absence of light played a minor role in the color change of groundwood. However, in the presence of ultra-violet light there was a marked change. This seemed to indicate there was an appreciable photochemical effect on the groundwood pulp. The authors (11) also reported that the action of the ultra-violet light on the lignin was the cause of at least a part of the yellowing of the groundwood pulp.

THE VARIATIONS WITH pH

The pH of the groundwood sample, both before and after treatment with ultra-violet light, has a large influence on the brightness of the pulp. The optimum pH

for the highest brightness was found to be in the vicinity of 4.0.(7), a fact which was verified by Lewis, Reineck, and Fronmuller.(6)

THE VARIATION WITH OXYGEN AND OZONE

The presence of oxygen in the atmosphere of the irradiated sheet should also be considered. It was found that groundwood fades faster in the presence of atmospheric oxygen than when it is not present.(11) Launer and Wilson (10) established that newsprint subjected to ultra-violet light in the absence of oxygen increased in brightness when the temperature was controlled. If the sheet was subsequently exposed to elevated temperatures, the brightness dropped to its original level. When oxygen was present during the controlled temperature irradiation, the brightness dropped. Other authors (7) stated that the role of oxygen in fading of groundwood was small. They also pointed out that ozone alone brightened groundwood, but in the presence of ozone and ultra-violet light, the brightness dropped twice as much as with ultra-violet light alone.

HOW ULTRA-VIOLET LIGHT AFFECTS UNBLEACHED CHEMICAL PULPS

Little information is available on the action of ultra-violet light on chemical pulps, but Graff (9) did report that the brightness of unbleached spruce sulphite decreased extensively for the first day, under the action of a Sterilamp and of the sun. Further decreases in brightness were noted, but were much more gradual.

surprisingly, the report showed that the brightness of a hardwood pulp, unbleached basswood sulphite, increased, after a slight initial decrease. It was also found that coniferous unbleached kraft and soda pulps showed a gradual increase in brightness when exposed to ultra-violet light.

When Launer and Wilson (10) exposed soda-sulphite and refined sulphite sheets to ultra-violet light at controlled temperature, the brightness increased. However, they found that in the absence of temperature control, both types of paper yellowed. Another interisting aspect of their investigation showed that this yellowing, caused by heat, could be bleached out with light. Inversely, bleaching caused by light could be nullified by heat. They also reported that light did not cause yellowing, but that the treated fibers exhibited, upon aging, relatively rapid changes which were not photochemical. Launer and Wilson showed that soda-sulphite papers, irradiated with ultra-violet light under controlled temperature in absence of oxygen brightened, but that the brightness increase was smaller than in the presence of oxygen under controlled temperature conditions.

Lewis,Reineck, and Fronmuller (6) found that both bleached and unbleached sulphite faded when exposed to sunlight for 35 hours. It was not stated whether this was deciduous or coniferous pulp.

Because of the seeming lack of knowledge of the effects which ultra-violet light has on unbleached high

yield pulps and to better study and understand the effects of ultra-violet light on unbleached chemical pulps, an experimental study will be undertaken.

REFERENCES

(1) Encyclopedia Britannica, Vol. 14, p. 57-58, Encyclopedia Britannica, Inc. (1955)

(2) Encyclopedia Britannica, Vol. 14, p.58, Encyclopedia Britannica, Inc. (1955)

(3) Webster's New International Dictionary, Second Edition G. and C. Merriam Company, Springfield, Mass. (1957)

(4) TAPPI Standard T216-m47

(5) Sutermeister, Edwin, "Chemistry of Pulp and Paper Making", Third Edition, John Wiley and Sons New York (1941), p. 284

(6) Lewis, Harry F., Reineck, E. A., and Fronmuller, D., The "Fading" of Groundwood by Light. I. A Study of the Relation between the Variables in Sheet Formation and Fading. Technical Association Papers 28: 157-162 (June,1945); Paper Trade Journal 121, no. 8:44-8(Aug. 23, 1945)

(7) Van den Akker, J. A., Lewis, H. F., Jones G. W., and Buchanan, M. A. The Nature of the Color Changes in Groundwood. Tappi 32, no. 4:187-192 (April,1949)

(8) Forman, L. V. Action of Ultraviolet Light on Lignin Paper Trade Journal 111, no.21:34-40(Nov. 21,1940); Technical Association Papers 24:602-608(1941)

(9) Graff, J. H. Stain Reactions of Pulps Exposed to Ultraviolet Light. Paper Trade Journal 113, no. 13: 100-104(Sept. 25, 1941); Technical Association Papers 25,no. 1:612-617(1942)

(10) Launer, H. F., and Wilson, W. K. The Photochemical Stability of Papers. Paper Trade Journal 116, no.8: 28-36(Feb. 25,1943); Technical Association Papers, 26:139-147(June,1943)

(11) Nolan, Philip, Van den Akker, J. A., and Wink, W. A. The "Fading" of Groundwood by Light. II. The Physical Mechanism of Fading. Technical Asscciation Papers 28:162-166(June,1945); Paper Trade Journal 121, no.11:33-37(Sept. 13,1945)

THE EFFECTS OF ULTRAVIOLET LIGHT ON THE COLOR OF UNBLEACHED PULPS

EXPERIMENTAL DESIGN

Throughout the literature survey there was found only limited information on the effects of ultraviolet light on any of the high yield unbleached pulps. It was decided, in view of the recent interest shown for these pulps, to undertake some experimental work.

Two groups of pulps will be studied as to the effect of ultraviolet light on their color. The first group, the high yield pulps, will include cold caustic soda pulp, neutral sulphite semi-chemical pulp, groundwood, and chemi-groundwood pulp. The second group of pulps will include chemical woodpulps: kraft, sulphite, and soda pulps. These will also be in unbleached condition.

The pulps will be formed into handsheets for optical testing according to TAPPI Standards, with special emphasis placed on the removal of residual chemicals before the start of the experimental work.

Variables in the experiments include time of exposure to ultraviolet light and the pH at which the sheets are formed. The effects of ultraviolet light will be checked after 0, 4, 12, 24, and 48 hours of exposure. The pH of the sheets being exposed will be 4, 7, and 10. Adjustments to these pH levels will be made with alum or Sulphuric acid on the one hand, and with sodium hydroxide or sodium aluminate on the other hand. Six sets of handsheets will be made to determine what, if any, differences are caused

by varying the pH by two different chemicals.

The equipment to be used for the irradiation of the samples will be a Fade-Ometer. All sheets will be checked by means of the I. P. C. Brightness Tester for brightness and yellowness. If time permits, color curves will be established, and if so, all filters of the I. P. C. instrument will be used.

MATERIALS

The materials used in forming the Optical Brightness Pads were unbleached pulps ranging from high yield chemi-groundwood pulp to well cooked sulphites. These pulps were:

1. Hardwood Chemi-groundwood
2. Hardwood Sulphite
3. Hardwood Soda
4. Hardwood N.S.S.C.(70% yield)
5. Hardwood N.S.S.C.(78% yield)
6. Hardwood Cold soda
7. Coniferous Kraft
8. Coniferous Sulphite

METHODS

The forming of the Optical Brightness Pads was done according to TAPPI Standard T-218, with the exception that the pH values were adjusted to definite levels. The reagents used to obtain these pH levels were 1% sulphuric acid and 5% papermaker's alum on the acid side, as well as 1% sodium hydroxide and 5.25% sodium aluminate on the basic side.

All samples were irradiated in a type FDA-R Fade-Ometer manufactured by the Atlas Electric Devices Company. The samples were exposed to the ultraviolet rays of the Fade-Ometer for periods of four, twelve, twenty-four, and fourty-eight hours. Complete color curves, ie., reflectance values determined with the nine filters of the I.P.C. Brightness Tester, were taken before any irradiation of the sample and after 48 hours of irradiation. Partial color curves, ie., reflectance values for filters 1, 2, 5, 7, and 9, were produced for the samples after 4, 12, and 24 hours of irradiation, because of the time factor involved in using all filters. After each period of ultraviolet exposure, a one inch sample

was cut from the original specimen so that a visual comparison of the progress caused by irradiation could be made.

EQUIPMENT USED

The Fade-Ometer is an electrically operated device used to approximate the irradiation of noon June sunlight both qualitatively and quantitatively. Four and two third hours in the Fade-Ometer is equivalent to six hours in the standard outdoor sun test. The Fade-Ometer gives this type of irradiation continuously and hence is valuable for accelerated tests.

The ambient air temperature at the face of the specimens is controlled to within ± 3° F, if the temperature control is set between 95 and 150° F. There is also a dial type thermometer which gives the ambient temperature in accordance with the specification of the A.S.T.M. The Fade-Ometer has a ventilating system for controlling the temperature in the test chamber. This system incorporates filtered air and is controlled by an electrically operated blower which is actuated by a thermo-regulator.

Humidity is adjusted by a constant level reservoir which adds moisture to filtered air by means of evaporation from a set of wicks partially submerged in the reservoir. Depending upon atmospheric conditions and the condition of the wicks, the relative humidity may be up to 50% in the test chamber.

The test specimens were held in a vertical position supported at both the top and bottom. The specimen holders used were type SL-LSR stainless steel holders, giving an exposure area of 1 3/4" x 5".

The ultraviolet light is produced by the Atlas Violet

Carbon Arc. This arc gives a continuous spectrum of light from 279 mu to 20,000 mu. The arc is produced by passing a controlled current between one solid carbon electrode and two cored electrodes or vice versa. The arc is encased in a Pyrex globe which filters out the shorter wavelengths so that the radiation at the sheets will approximate summer sunlight. The globe also protects the samples from the products of combustion of the arcs and gives extended life to the electrodes.

All recorded values for all filters were obtained by means of the I.P.C. Brightness Tester. The recorded values are the average of three or more readings. The I.P.C. Brightness Tester is a photoelectric instrument which measures the reflectance of a sample, as compared to the reflectance of a magnesium oxide block.

The light is incident upon the samples at a 45° angle. The reflected light passes through a series of lenses and one of the nine filters into an active phototube. The current created in the phototube is regulated to oppose a current set up in a dummy phototube. When a current balance is set up, the reflectance reading is taken from a vernier brightness scale.

The effective wavelength of reflected light corresponding to each of the filters is as follows:

Filter	1	457 millimicrons
	2	400
	3	439
	4	491
	5	537
	6	571
	7	606
	8	630
	9	651

The standard, which was used to get the reflectance values, was obtained through subscription to the Institute of Paper Chemistry.

DISCUSSION OF RESULTS

Figures 1-8 show the color curves of the eight pulps before irradiation and after 48 hours of irradiation. The color curves shown are for the pulp samples without pH control and are the average of two such samples.

Of these eight pulps, three showed an increase in percent reflectance at each filter over the 400 mu. to 650 mu. range caused by ultraviolet irradiation. Two of these pulps, the unbleached hardwood soda and the unbleached coniferous kraft showed a nearly equal increase in reflectance over this range. The third sample, unbleached hardwood sulphite, showed only a mild increase in reflectance in the blue and violet ranges, but a much larger increase in reflectance in the red, orange, and yellow range.

The remaining five pulps when exposed to ultraviolet light showed a loss in percent reflectance in the blue and violet range, but exhibited varying results in the longer wavelength regions. Both unbleached hardwood N.S.S.C.(70% yield) and unbleached coniferous sulphite showed a loss in reflectance at all wavelengths in the visable region. However, the reflectance difference was noticeable smaller in the longer wavelength regions. Unbleached hardwood cold soda and unbleached hardwood chemi-groundwood pulp color curves, before irradiation and after 48 hours irradiation, were characterized by a loss in reflectance in the shorter wavelength regions, and a convergence of the color curves in the orange region. In the red-orange regions, the percent reflectance of the irradiated samples was greater than that

of the non-irradiated samples. The unbleached hardwood N.S.S.C.(78% yield) pulp was lower in percent reflectance after irradiation up to the yellow-green region but had a higher percent reflectance than the non-irradiated pulp after this point.

The samples, adjusted to a pH level of four with papermakers' alum, although not having the lowest color values before the sheets were irradiated, lost more in percent reflectance than the pulps adjusted to other pH levels. In most cases the color curve of the alum adjusted sample was the lowest after 48 hours of irradiation.

When sulphuric acid was used to adjust the pH level to four, the color curve was, in general, the highest of any of the sheets tested, both before and after irradiation. The one case which was obviously different was unbleached coniferous sulphite. There the color curves for the control sheets were higher before and after irradiation than the sulphuric acid adjusted sheets.

The test sheets which were adjusted to a pH level of ten with either sodium hydroxide or sodium aluminate can best be discussed by comparing them with each other and also against the alum adjusted sheets.

For all pulps tested either the sodium hydroxide or the sodium aluminate adjusted sheets had the lowest color curve before irradiation. The values obtained in the presence of the two chemicals were very close, each having the lowest color curve in four cases. There was no change in the relative

location of the color curves between the two -- the one color curve that had the low values remained low for all filters and all exposure times.

The original color curves for alum adjusted sheets were above those of the pH ten sheets before irradiation. However, the alum adjusted sheets, after irradiation, lost more brightness in the cases of the five sheets that yellowed and gained less brightness in the cases of the three pulps which showed an increase in reflectance. This loss or gain moved the color curve of the alum adjusted sheets to a position lower than the location of the sheets to pH ten. The only exception to this fact was in the case of unbleached hardwood soda pulp.

Variables other than time and pH level which affect the color of unbleached pulp include temperature, composition of the surrounding atmosphere, and the presence of metallic ions. The temperature at the face of the samples was 110 $\pm$ 5°F. The atmosphere in which the samples were exposed may have contained some ozone formed by the arc of the Fade-Ometer. No effort, other than using distilled water in forming optical test pads, was made to free the sheets of metallic ions. The degree to which these variables affected the results was not explored.

CONCLUSIONS

From the limited number of experiments which were conducted we can conclude that:

1. Unbleached coniferous kraft, unbleached hardwood

sulphite, and unbleached hardwood soda pulps brightened when exposed to ultraviolet light.

2. Unbleached hardwood N.S.S.C.(70% yield), unbleached coniferous sulphite, unbleached hardwood cold soda, and unbleached hardwood chemi-groundwood pulps yellowed when exposed to ultraviolet light.

3. Adjusting the pH to four with sulphuric acid increased the reflectance of most pulps while adjusting the pH to ten with sodium hydroxide decreased the reflectance of the pulps. This was observed before irradiation with ultraviolet light.

4. When papermakers' alum was used to adjust the pH of the sheets to four, the reflectance values before irradiation decreased slightly in most cases. There was a larger drop in the reflectance value when the pH of the pulp is adjusted to the pH ten with sodium aluminate.

5. Both means of adjusting the pH to ten, namely sodium hydroxide and sodium aluminate; decreased the initial brightness of the pulp. However, there was little correlation between the effects of the two compounds used to adjust the pulp pH to four, namely sulphuric acid and papermakers' alum.

6. Experimental results showed that none of the compounds used in pH control stabilized consistently the color of unbleached pulp exposed to ultraviolet irradiation.

EXPLANATION OF CODE

The sheet numbers C_1 and C_2 indicate test sheets which had no pH control. The subscripts were used for identifying the sheets during testing. In all other cases the initial A indicated the stock slurry was adjusted to a definite pH level. The remaining letter(s) tells what chemical was used to adjust the pH. The code used for these chemicals was:

A — papermaker's alum

SA - sodium aluminate

H_2 - sulphuric acid

Na - sodium hydroxide

The number in parenthesis was the pH of the stock slurry from which the brightness were formed.

I. P. C. BRIGHTNESS TESTER REFLECTANCE VALUES FOR COLOR CURVES

UNBLEACHED HARDWOOD CHEMI-GROUNDWOOD

Sheet Number	Filter 2 400 mu	Filter 3 439 mu	Filter 1 457 mu	Filter 4 491 mu	Filter 5 537 mu	Filter 6 571 mu	Filter 7 606 mu	Filter 8 630 mu	Filter 9 651 mu
	EXPOSURE TIME — 0 Hours								
C_1 (6.5)	37.8	50.4	53.0	58.0	63.1	66.9	71.0	74.4	76.8
C_2 (6.5)	38.6	51.3	53.4	58.5	63.5	68.3	71.3	74.5	76.8
ANa (7)	38.0	50.0	52.4	57.5	62.2	66.1	69.5	73.1	75.1
ASa (7)	35.6	47.2	49.7	55.5	60.2	64.5	67.5	71.3	74.2
AA (4)	35.4	47.5	49.8	56.3	61.2	65.7	67.9	71.8	74.5
AH_2 (4)	38.5	51.9	53.9	58.7	64.4	68.7	72.5	74.4	77.8
ANa (10)	34.9	46.1	48.2	53.1	57.7	62.5	66.3	69.6	72.2
ASA (10)	35.5	46.4	48.9	53.4	58.1	62.9	66.6	69.7	73.2
	EXPOSURE TIME —4 Hours								
C_1 (6.5)	32.5	45.5	47.5	54.5	60.6	66.8	69.4	73.1	75.5
C_2 (6.5)	32.8	46.0	48.6	54.6	60.9	66.2	69.4	73.1	75.4
ANa (7)	32.6	45.2	47.6	54.0	60.0	64.9	67.8	72.0	74.4
ASA (7)	30.6	43.2	45.6	52.4	58.5	63.5	67.3	70.5	72.3
AA (4)	30.1	42.2	44.3	51,7	58.3	63.4	67.9	70.6	73.7
AH_2 (4)	32.7	46.1	48.5	55.1	61.6	67.4	71.1	74.5	77.0
ANa (10)	31.5	43.3	45.5	51.5	57.3	62.6	66.0	69.8	73.0
ASA (10)	31.9	43.2	45.7	52.3	57.9	63.3	66.7	70.8	73.5
	EXPOSURE TIME — 12 Hours								
C1 (6.5)	26.5	41.3	44.4	52.3	60.3	66.4	71.2	74.4	76.6
C_2 (6.5)	27.0	41.3	44.7	52.8	60.8	67.0	70.4	74.5	76.7
ANa (7)	27.4	40.9	44.6	52.2	59.6	65.8	70.1	73.4	75.5
ASA (7)	26.2	39.4	42.7	50.4	58.1	63.6	68.1	71.3	74.6
AA (4)	24.1	37.5	40.8	49.3	57.4	63.3	69.5	72.0	74.3
AH_2 (4)	26.3	40.7	44.5	52.4	60.9	67.4	72.7	75.6	77.4
ANa (10)	26.3	39.9	43.3	50.5	58.0	63.7	69.9	71.4	74.0
ASA (10)	27.2	40.5	43.5	51.0	59.9	64.6	69.3	71.8	74.5
	EXPOSURE TIME — 24 Hours								
C_1 (6.5)	24.6		42.0		59.1		70.2		76.9
C_2 (6.5)	24.4		41.7		59.0		70.1		76.2
ANa (7)	24.5		41.7		58.2		70.0		75.6
ASA (7)	23.5		40.1		57.2		68.5		75.1
AA (4)	22.1		38.2		55.9		68.0		74.8
AH_2 (4)	24.2		40.9		59.0		71.6		78.1
ANa (10)	24.6		40.7		57.3		68.2		74.7
ASA (10)	24.6		40.9		57.6		69.0		75.8
	EXPOSURE TIME—48 HOURS								
C_1 (6.5)	18.4	29.6	33.7	42.9	54.1	63.1	70.6	75.6	78.2
C_2 (6.5)	17.9	28.8	32.9	42.4	53.9	63.3	70.4	75.3	78.4
ANa (7)	17.6	28.8	33.2	42.6	53.7	62.8	70.2	74.7	77.6
ASA (7)	16.7	28.1	32.2	41.2	52.3	61.4	68.2	72.7	76.1
AA (4)	15.7	26.0	29.6	38.2	49.3	58.8	66.2	71.2	74.5
AH_2 (4)	17.1	27.6	31.8	41.1	52.4	62.5	69.5	75.1	78.7
ANa (10)	17.6	28.8	32.7	41.9	53.1	62.5	69.2	73.5	77.1
ASA (10)	17.8	29.0	33.2	42.3	53.4	62.7	69.3	74.1	77.2

I. P. C. BRIGHTNESS TESTER REFLECTANCE VALUES FOR COLOR CURVES

UNBLEACHED HARDWOOD SULPHITE

Sheet Number	Filter 2 400 mu	Filter 3 439 mu	Filter 1 457 mu	Filter 4 491 mu	Filter 5 537 mu	Filter 6 571 mu	Filter 7 606 mu	Filter 8 630 mu	Filter 9 651mu
	EXPOSURE TIME -- 0 Hours								
C_1 (7.1)	39.0	47.4	49.7	54.6	59.3	63.2	67.1	69.5	71.7
C_2 (7.1)	39.4	47.9	49.9	55.3	59.6	63.6	67.1	70.0	72.4
AA (4)	34.9	42.2	44.7	51.2	56.0	60.6	63.1	66.6	69.3
AH_2 (4)	40.5	49.5	51.8	56.9	61.8	66.0	70.0	72.6	74.7
ANa (10)	39.6	47.5	49.7	54.9	58.9	62.9	65.7	68.6	71.3
ASA (10)	35.3	42.8	44.5	49.8	54.1	57.7	61.3	64.0	66.3
	EXPOSURE TIME -- 4 Hours								
	No change was noticable upon visual inspection of the sheets, so no values were recorded.								
	EXPOSURE TIME -- 12 Hours								
C_1 (7.1)	37.3		50.0		57.6		69.5		74.3
C_2 (7.1)	38.2		50.9		58.1		70.7		75.4
AA (4)	33.4		45.8		54.4		67.3		72.4
AH_2 (4)	39.2		51.6		59.6		72.3		77.4
ANa (10)	38.4		49.9		57.0		68.1		73.3
ASA (10)	33.4		44.7		51.6		63.5		67.4
	EXPOSURE TIME -- 24 Hours								
C_1 (7.1)	37.7		50.7		62.5		70.2		75.4
C_2 (7.1)	38.9		51.3		63.1		71.3		76.6
AA (4)	33.3		45.7		58.7		67.4		72.7
AH_2 (4)	40.0		52.1		64.7		74.0		79.0
ANa (10)	38.6		50.3		61.9		70.0		74.6
ASA (10)	33.3		44.7		55.7		62.6		67.9
	EXPOSURE TIME -- 48 Hours								
C_1 (7.1)	39.1	48.8	51.0	57.1	63.5	68.4	71.7	75.0	76.8
C_2 (7.1)	40.3	49.2	52.0	57.9	64.1	68.9	72.5	75.5	77.5
AA (4)	34.5	44.0	46.5	52.9	59.4	64.1	68.5	71.2	73.7
AH_2 (4)	41.4	50.7	53.2	59.1	65.7	70.7	74.4	77.2	80.3
ANa (10)	39.6	48.6	50.9	57.0	63.2	67.9	70.9	74.3	76.2
ASA (10)	34.1	42.7	45.1	50.6	56.2	60.2	63.2	66.1	68.5

I. P. C. BRIGHTNESS TESTER REFLECTANCE VALUES FOR COLOR CURVES

UNBLEACHED HARDWOOD N. S. S. C. (78% YIELD)

Sheet Number	Filter 2 400 mu	Filter 3 439 mu	Filter 1 457 mu	Filter 4 491 mu	Filter 5 537 mu	Filter 6 571 mu	Filter 7 606 mu	Filter 8 630 mu	Filter 9 651 mu
	EXPOSURE TIME — 0 Hours								
C_1 (6.8)	20.0	29.4	32.6	38.7	44.6	50.6	55.8	60.3	63.4
C_2 (6.8)	20.2	30.4	32.5	38.6	44.8	51.1	56.0	60.7	64.4
AA (4)	19.8	29.0	31.4	37.5	44.6	50.6	56.2	61.3	65.2
AH_2 (4)	20.9	31.5	33.3	39.8	46.4	52.8	59.2	63.4	67.1
ANa (10)	17.4	27.0	29.3	35.5	41.5	47.0	52.2	57.4	60.1
ASA (10)	18.2	27.6	30.2	35.8	41.7	47.6	53.3	57.8	62.3
	EXPOSURE TIME — 4 Hours								
No change was noticeable upon visual inspection of the sheets, so no values were recorded.									
	EXPOSURE TIME — 12 Hours								
C_1 (6.8)	20.0	29.8	32.5	39.2	46.4	52.3	57.4	62.6	65.9
C_2 (6.8)	19.9	30.2	32.9	39.4	46.8	52.8	58.2	62.7	65.6
AA (4)	17.5	27.2	30.1	36.7	44.9	51.7	56.9	62.6	65.4
AH_2 (4)	19.7	30.4	32.9	39.6	48.3	54.6	60.4	64.2	67.3
ANa (10)	18.6	28.5	30.6	37.6	43.4	49.3	55.0	60.0	63.1
ASA (10)	19.4	28.6	31.2	37.2	44.6	50.4	55.9	60.6	63.9
	EXPOSURE TIME — 24 Hours								
C_1 (6.8)	18.3		31.1		46.8		59.5		67.1
C_2 (6.8)	18.0		31.1		45.6		59.2		66.8
AA (4)	15.8		28.1		43.9		57.6		66.2
AH_2 (4)	18.4		31.0		46.9		60.3		67.8
ANa (10)	17.1		29.5		44.3		56.3		64.8
ASA (10)	17.6		30.0		44.7		57.5		65.5
	EXPOSURE TIME — 48 Hours								
C_1 (6.8)	14.9	24.3	27.3	35.2	45.1	53.3	59.9	65.6	69.5
C_2 (6.8)	14.7	24.0	27.1	35.0	44.4	52.7	59.6	65.1	68.8
AA (4)	12.6	21.0	24.0	31.5	40.9	49.4	56.5	61.9	65.5
AH_2 (4)	14.7	23.9	26.8	34.6	44.6	53.6	60.7	65.8	69.8
ANa (10)	14.3	23.4	26.4	33.7	42.6	50.6	57.5	63.1	66.9
ASA (10)	14.6	23.8	26.7	34.2	43.3	51.6	57.9	63.5	67.6

I. P. C. BRIGHTNESS TESTER REFLECTANCE VALUES FOR COLOR CURVES

UNBLEACHED HARDWOOD COLD SODA

Sheet Number	Filter 2 400 mu	Filter 3 439 mu	Filter 1 457 mu	Filter 4 491 mu	Filter 5 537 mu	Filter 6 571 mu	Filter 7 606 mu	Filter 8 630 mu	Filter 9 651 mu
	EXPOSURE TIME — 0 Hours								
C_1 (7.1)	26.7	43.4	46.5	54.1	61.3	67.3	72.1	76.3	79.2
C_2 (7.1)	26.6	42.9	46.1	53.8	60.8	67.2	71.8	76.0	79.1
AA (4)	26.7	42.6	45.3	53.0	60.2	65.9	70.3	74.0	77.0
AH_2 (4)	27.9	45.2	48.5	56.2	64.0	70.0	75.0	78.5	81.2
ANa (10)	26.6	42.0	45.1	52.5	59.0	65.3	70.0	74.1	77.0
ASA (10)	25.5	40.7	43.7	50.8	57.3	62.9	68.3	72.2	75.4
	EXPOSURE TIME — 4 Hours								
C_1 (7.1)	26.0		44.5		60.2		72.7		78.5
C_2 (7.1)	26.0		43.8		59.8		71.7		78.5
AA (4)	23.5		41.7		58.0		69.2		76.0
AH_2 (4)	27.5		45.9		62.9		75.4		81.1
ANa (10)	26.3		43.4		58.9		70.7		77.9
ASA (10)	25.5		42.0		56.7		67.6		75.0
	EXPOSURE TIME — 12 Hours								
C_1 (7.1)	21.0		39.6		59.0		72.5		80.2
C_2 (7.1)	21.0		39.4		58.8		72.3		80.1
AA (4)	17.7		35.6		55.3		68.0		75.1
AH_2 (4)	21.0		39.7		60.5		74.5		82.3
ANa (10)	21.4		39.3		57.9		70.8		78.5
ASA (10)	20.8		38.2		55.5		67.8		75.4
	EXPOSURE TIME — 24 Hours								
C_1 (7.1)	19.9		36.4		55.9		70.3		78.2
C_2 (7.1)	20.1		36.4		55.7		70.1		77.8
AA (4)	17.8		33.8		52.8		67.2		74.7
AH_2 (4)	20.1		36.8		57.3		72.6		80.2
ANa (10)	20.3		36.3		55.2		69.9		77.4
ASA (10)	19.5		34.8		52.8		66.1		74.2
	EXPOSURE TIME — 48 Hours								
C_1 (7.1)	18.1	29.6	33.2	42.9	54.5	64.0	70.8	76.1	79.5
C_2 (7.1)	18.5	29.4	33.3	43.2	54.6	64.1	70.9	76.2	79.8
AA (4)	16.4	26.8	30.1	39.5	50.5	59.8	66.1	70.3	74.4
AH_2 (4)	17.6	29.1	32.8	42.5	54.5	64.9	72.9	77.3	80.3
ANa (10)	18.5	29.2	33.1	42.7	53.9	63.2	70.4	75.3	78.5
ASA (10)	17.3	28.1	31.7	41.1	51.7	60.6	67.4	71.9	75.4

I. P. C. BRIGHTNESS TESTER REFLECTANCE VALUES FOR COLOR CURVES

UNBLEACHED CONIFEROUS SULPHITE

Sheet Number	Filter 2 400 mu	Filter 3 439 mu	Filter 1 457 mu	Filter 4 491 mu	Filter 5 537 mu	Filter 6 571 mu	Filter 7 606 mu	Filter 8 630 mu	Filter 9 651 mu
EXPOSURE TIME -- 0 Hours									
C_1 (7.0)	47.4	58.3	60.3	65,1	70.0	74.5	78.1	80.7	81.5
C_2 (7.0)	45.6	56.5	59.1	64.1	68.5	72.9	76.3	79.2	81.1
AA (4)	37.4	47.6	50.3	55.3	61.2	66.1	69.5	72.3	74.3
AH_2 (4)	42.9	54.8	57.1	62.7	68.2	72.8	77.8	79.2	81.3
ANa (10)	40.4	52.4	54.1	60.6	65.9	70.0	74.5	77.1	79.1
ASA (10)	37.4	48.9	50.9	57.7	64.3	69.7	74.5	77.8	79.7
EXPOSURE TIME -- 4 Hours									
C_1 (7.0)	40.6		54.6		67.2		76.2		81.5
C_2 (7.0)	40.0		53.9		66.3		74.5		80.2
AA (4)	32.7		46.1		58.4		67.2		72.0
AH_2 (4)	38.4		51.7		65.2		74.9		80.0
ANa (10)	38.6		52.4		64.2		72.9		78.8
ASA (10)	35.1		49.6		62.7		73.0		78.9
EXPOSURE TIME -- 12 Hours									
C_1 (7.0)	37.9		52.7		67.1		76.1		82.7
C_2 (7.0)	36.7		51.5		64.6		75.9		80.5
AA (4)	30.2		44.1		57.8		66.8		72.5
AH_2 (4)	35.8		50.0		63.8		75.4		81.8
ANa (10)	36.2		50.0		63.3		73.8		79.0
ASA (10)	33.1		47.4		62.0		73.2		79.3
EXPOSURE TIME -- 24 Hours									
C_1 (7.0)	34.9		49.9		64.3		74.4		81.8
C_2 (7.0)	34.9		49.2		63.6		73.9		80.7
AA (4)	28.0		41.1		54.8		64.8		70.4
AH_2 (4)	33.5		48.1		62.5		75.1		81.6
ANa (10)	34.6		48.4		62.9		73.1		79.2
ASA (10)	31.0		45.8		61.0		71.8		78.9
EXPOSURE TIME -- 48 Hours									
C_1 (7.0)	36.2	46.0	48.4	56.0	63.9	71.2	74.6	79.2	81.4
C_2 (7.0)	34.9	44.7	47.0	54.1	62.0	68.7	73.9	77.6	80.4
AA (4)	28.2	37.7	40.2	47.3	54.7	60.7	65.2	68.6	71.4
AH_2 (4)	34.4	43.8	46.4	53.9	61.9	68.9	74.6	77.9	80.5
ANa (10)	34.6	44.5	47.0	54.2	61.4	68.5	72.6	76.5	79.0
ASA (10)	32.0	42.6	45.1	52.4	60.3	67.2	72.2	76.1	78.7

I. P. C. BRIGHTNESS TESTER REFLECTANCE VALUES FOR COLOR CURVES

UNBLEACHED HARDWOOD N. S. S. C. (70% YIELD)

Sheet Number	Filter 2 400 mu	Filter 3 439 mu	Filter 1 457 mu	Filter 4 491 mu	Filter 5 537 mu	Filter 6 571 mu	Filter 7 606 mu	Filter 8 630 mu	Filter 9 651 mu
	EXPOSURE TIME -- 0 Hours								
C_1 (7.0)	29.2	43.6	47.2	54.1	59.7	64.0	69.4	71.9	75.7
C_2 (7.0)	28.2	43.3	45.9	53.1	59.0	63.5	68.5	72.0	74.7
AA (4)	29.8	41.9	45.5	53.2	60.1	65.6	69.5	72.7	74.8
AH_2 (4)	31.6	45.9	49.2	56.1	62.3	67.1	70.9	73.5	76.3
ANa (10)	27.9	40.8	43.9	49.9	56.0	61.3	65.9	70.7	73.5
ASA (10)	28.5	41.5	44.5	50.9	57.2	62.3	66.9	71.3	74.4
	EXPOSURE TIME -- 4 Hours								
No change was noticeable upon visual inspection of the sheets, so no values were recorded.									
	EXPOSURE TIME -- 12 Hours								
C_1 (7.0)	20.7		36.8		52.9		64.6		71.0
C_2 (7.0)	20.5		36.9		52.9		64.9		71.8
AA (4)	18.4		33.5		51.0		63.4		71.9
AH_2 (4)	22.1		39.0		56.0		69.0		74.9
ANa (10)	20.8		36.4		51.3		63.7		70.4
ASA (10)	21.3		36.8		52.3		64.2		71.7
	EXPOSURE TIME -- 24 Hours								
C_1 (7.0)	19.2		34.6		51.5		64.3		72.0
C_2 (7.0)	18.7		34.4		51.5		64.3		72.0
AA (4)	17.4		31.7		49.7		63.3		72.0
AH_2 (4)	20.7		36.3		54.6		68.7		75.7
ANa (10)	19.6		34.7		50.7		63.4		71.1
ASA (10)	20.1		34.9		51.3		64.3		72.0
	EXPOSURE TIME -- 48 Hours								
C_1 (7.0)	16.6	28.2	31.2	40.1	49.5	57.4	63.5	68.9	72.1
C_2 (7.0)	16.8	28.2	31.5	40.1	49.6	57.6	63.8	69.0	72.1
AA (4)	15.4	25.5	28.4	36.9	47.0	55.4	62.0	67.7	71.3
AH_2 (4)	18.9	29.3	32.8	41.8	52.2	61.2	67.1	72.6	75.9
ANa (10)	17.9	28.7	31.8	40.2	49.7	57.0	64.0	68.8	72.3
ASA (10)	18.4	28.9	32.2	40.5	49.8	57.5	63.7	68.5	72.2

I. P. C. BRIGHTNESS TESTER REFLECTANCE VALUES FOR COLOR CURVES

UNBLEACHED HARDWOOD SODA

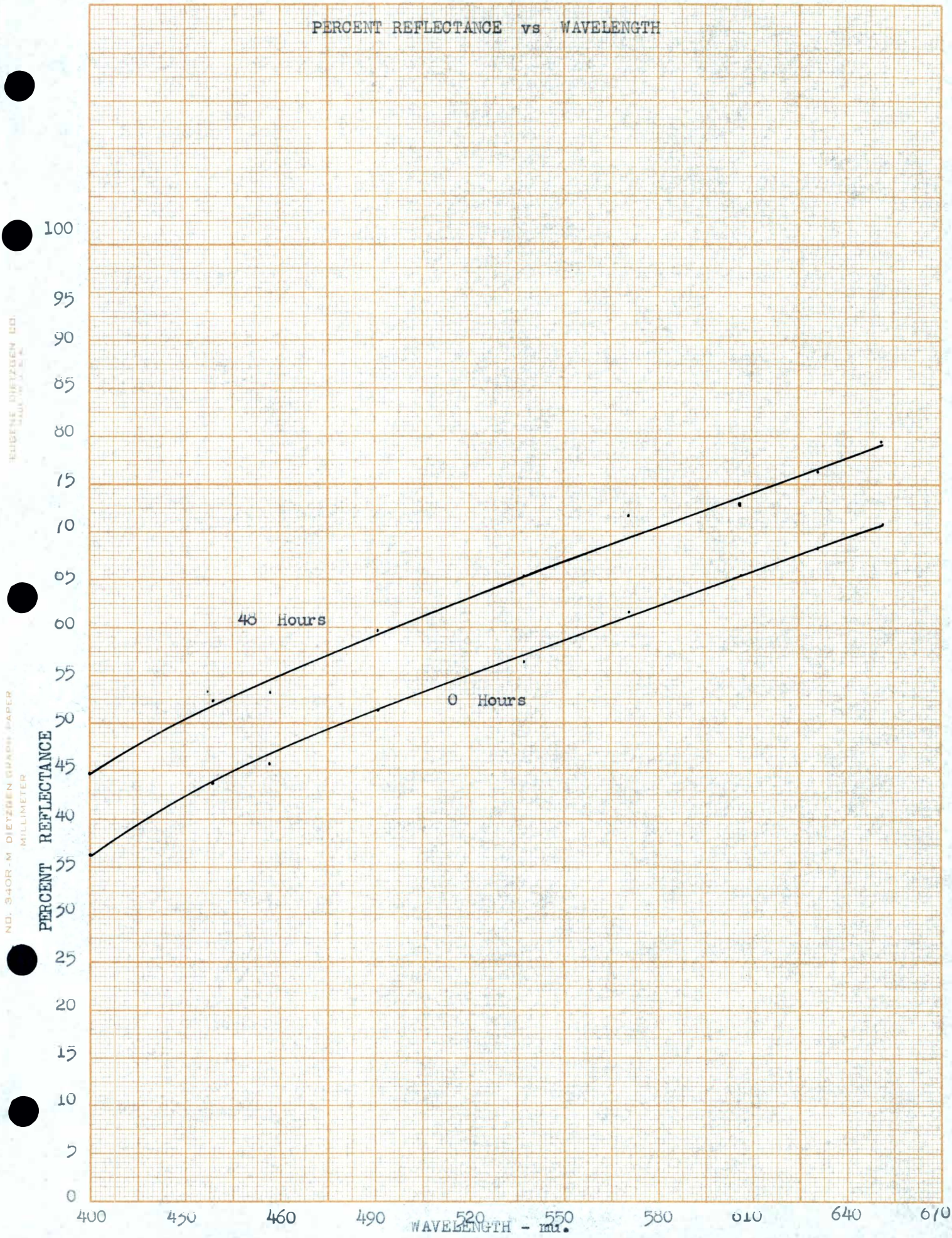
Sheet Number	Filter 2 400 mu	Filter 3 439 mu	Filter 1 457 mu	Filter 4 491 mu	Filter 5 537 mu	Filter 6 571 mu	Filter 7 606 mu	Filter 8 630 mu	Filter 9 651 mu
EXPOSURE TIME — 0 Hours									
C_1 (7.2)	36.5	43.5	45.8	51.4	56.6	61.6	65.5	68.2	70.5
C_2 (7.2)	36.0	43.7	45.7	50.8	56.4	61.5	65.0	68.3	70.5
AA (4)	35.4	43.0	45.3	50.5	56.3	61.2	65.1	68.9	71.2
AH_2 (4)	36.7	45.3	47.0	52.4	58.5	63.8	68.2	71.4	73.9
ANa (10)	35.3	43.0	44.8	50.2	55.7	60.0	64.0	67.6	70.0
ASA (10)	35.1	42.9	44.9	49.7	55.1	60.0	64.0	67.2	69.8
EXPOSURE TIME — 4 Hours									
C_1 (7.2)	38.8		47.8		58.5		67.5		72.9
C_2 (7.2)	38.4		47.9		58.6		67.9		73.0
AA (4)	38.3		47.9		59.1		67.8		73.2
AH_2 (4)	40.6		50.0		61.5		70.5		75.6
ANa (10)	37.8		47.2		58.0		67.1		72.4
ASA (10)	37.6		47.0		57.6		66.4		71.8
EXPOSURE TIME — 12 Hours									
C_1 (7.2)	39.7		49.0		59.9		68.2		74.2
C_2 (7.2)	40.0		49.2		60.1		68.5		74.1
AA (4)	40.0		49.3		60.4		68.6		74.1
AH_2 (4)	42.2		51.6		63.1		71.2		77.2
ANa (10)	39.6		48.4		59.3		67.8		73.3
ASA (10)	39.2		48.1		58.7		66.4		72.5
EXPOSURE TIME — 24 Hours									
C_1 (7.2)	42.0		51.1		62.0		69.6		75.6
C_2 (7.2)	42.3		51.4		62.3		70.3		75.7
AA (4)	41.6		51.0		62.2		69.9		74.9
AH_2 (4)	44.5		53.7		65.2		73.7		78.4
ANa (10)	41.9		51.0		61.6		69.7		75.0
ASA (10)	41.4		50.5		61.1		68.6		74.5
EXPOSURE TIME — 48 Hours									
C_1 (7.2)	44.4	51.9	54.1	59.2	64.7	69.2	72.1	75.6	78.8
C_2 (7.2)	44.8	52.6	54.5	59.8	65.5	70.2	74.0	76.7	79.5
AA (4)	42.4	50.7	53.4	58.4	64.0	68.9	71.8	74.5	76.7
AH_2 (4)	47.3	54.7	56.6	61.9	67.3	71.7	75.0	78.3	79.9
ANa (10)	44.1	51.9	53.8	59.0	64.6	69.4	73.1	75.7	77.7
ASA (10)	43.5	51.1	53.3	58.3	63.9	68.4	71.6	74.9	76.5

I. P. C. BRIGHTNESS TESTER REFLECTANCE VALUES FOR COLOR CURVES

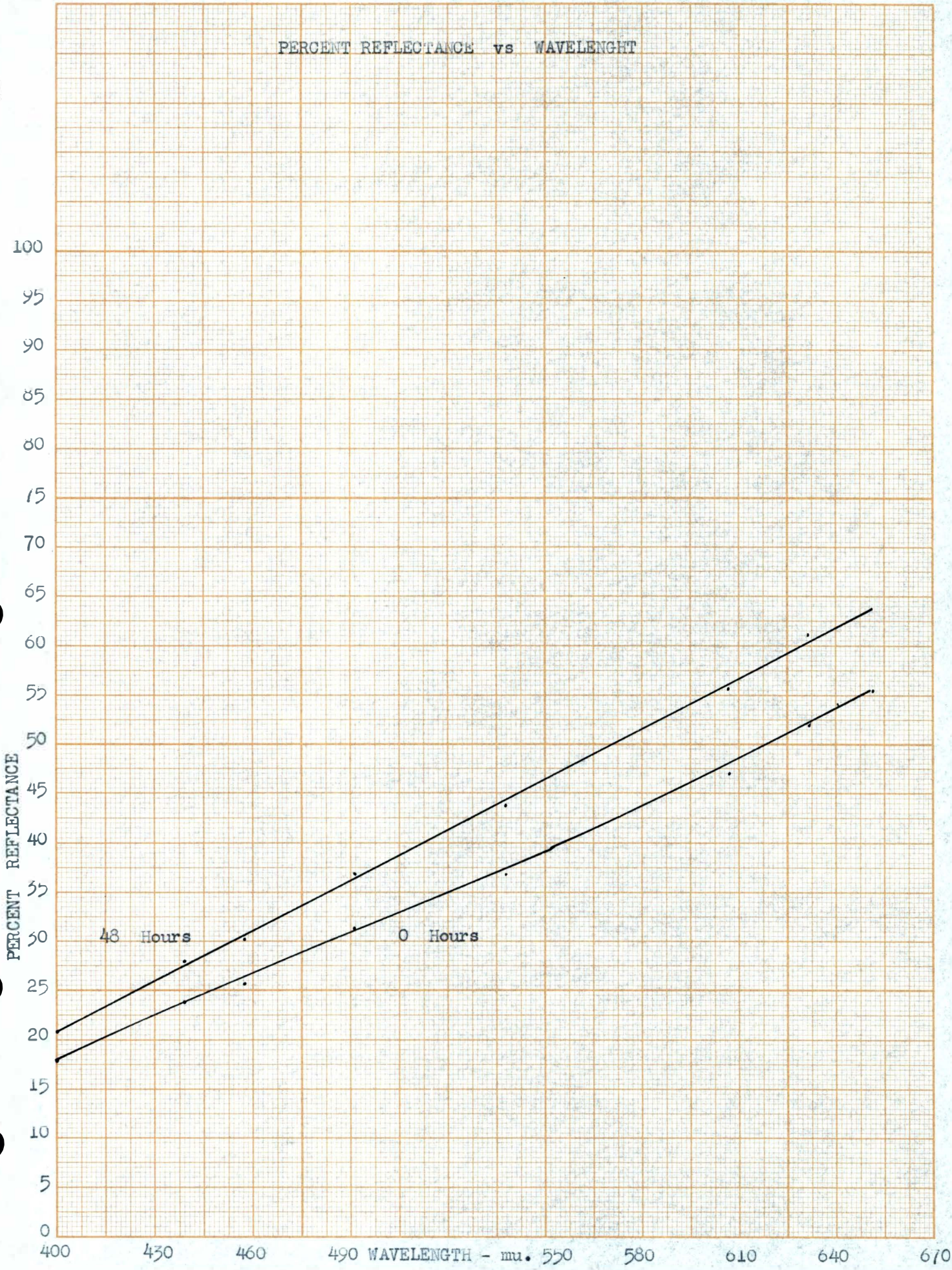
UNBLEACHED CONIFEROUS KRAFT

Sheet Number	Filter 2 400 mu	Filter 3 439 mu	Filter 1 457 mu	Filter 4 491 mu	Filter 5 537 mu	Filter 6 571 mu	Filter 7 606 mu	Filter 8 630 mu	Filter 9 651 mu
EXPOSURE TIME — 0 Hours									
C_1 (8.4)	17.3	24.4	25.9	31.4	36.9	42.3	47.3	52.0	55.8
C_2 (8.4)	16.7	23.5	25.6	31.1	36.5	41.9	46.8	51.8	55.5
AA (7)	17.2	24.0	25.3	30.4	36.0	41.4	46.4	51.6	54.9
AH_2 (7)	17.9	25.2	27.1	32.3	37.2	43.3	49.1	54.6	58.4
AA (4)	17.2	23.8	25.7	30.0	36.1	41.1	46.2	49.9	53.1
AH_2 (4)	18.5	26.3	28.0	33.4	39.0	46.3	52.8	57.6	61.8
ANa (10)	17.0	23.4	25.1	30.0	34.4	41.7	46.6	51.4	55.4
ASA (10)	17.4	24.5	25.9	31.1	35.6	42.8	48.2	52.7	56.6
EXPOSURE TIME — 4 Hours									
C_1 (8.4)	18.3		27.6		39.3		50.2-		58.2
C_2 (8.4)	17.7		26.9		38.2		49.4		56.8
AA (7)	18.3		27.3		39.0		49.9		57.7
AH_2 (7)	19.3		28.1		39.3		51.3		60.0
AA (4)	18.4		27.3		38.8		48.8		55.6
AH_2 (4)	20.0		29.5		40.7		54.2		62.7
ANa (10)	16.9		26.0		35.7		48.2		56.4
ASA (10)	18.0		27.6		37.4		49.8		57.4
EXPOSURE TIME — 12 Hours									
C_1 (8.4)	18.7		28.5		46.1		52.7		60.3
C_2 (8.4)	18.3		28.5		40.5		52.7		59.8
AA (7)	18.5		28.2		40.7		52.4		59.6
AH_2(7)	19.4		29.4		41.1		53.8		62.4
AA (4)	18.8		28.0		39.7		49.2		55.9
AH_2 (4)	20.1		30.3		42.3		56.2		64.9
ANa (10)	17.8		27.4		38.4		50.1		58.3
ASA (10)	18.1		27.8		38.8		51.1		59.4
EXPOSURE TIME — 24 Hours									
C_1 (8.4)	19.8		30.1		42.6		54.1		61.4
C_2 (8.4)	19.0		29.4		42.2		53.7		61.5
AA (7)	19.3		29.6		42.3		53.3		61.6
AH_2 (7)	20.9		30.8		42.8		55.4		62.8
AA(4)	18.9		28.6		40.8		50.1		57.6
AH_2 (4)	21.2		31.7		44.2		58.0		66.1
ANa (10)	18.3		27.7		38.9		51.5		58.8
ASA (10)	19.7		29.8		41.3		52.9		61.5
EXPOSURE TIME— 48 Hours									
C_1 (8.4)	21.0	28.2	30.4	36.6	43.7	50.1	55.5	60.0	63.6
C_2 (8.4)	20.9	28.1	30.3	36.6	43.7	50.2	56.1	60.4	64.1
AA (7)	21.0	27.8	30.2	36.4	43.4	50.0	55.3	60.1	63.9
AH_2 (7)	21.8	29.2	31.1	37.1	44.3	51.2	56.5	61.6	64.8
AA (4)	19.4	26.2	28.1	34.2	40.4	45.4	50.4	54.8	56.7
AH_2 (4)	21.9	28.8	31.4	37.0	44.2	52.5	58.9	63.7	67.2
ANa (10)	20.8	27.6	30.0	35.1	42.1	48.7	53.9	59.0	63.2
ASA (10)	20.8	27.8	30.1	35.4	42.2	49.2	54.6	59.5	63.6

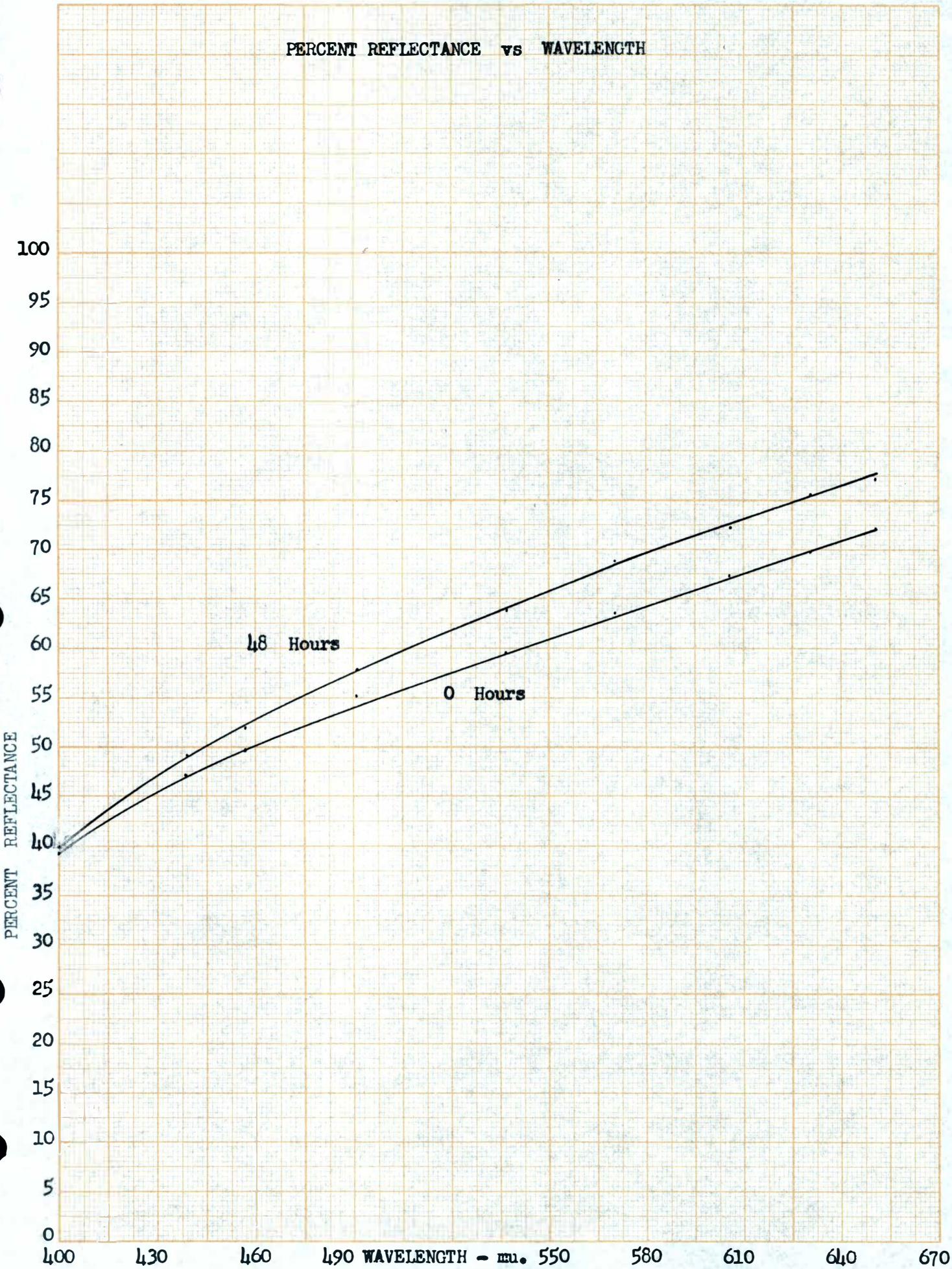
UNBLEACHED HARDWOOD SODA



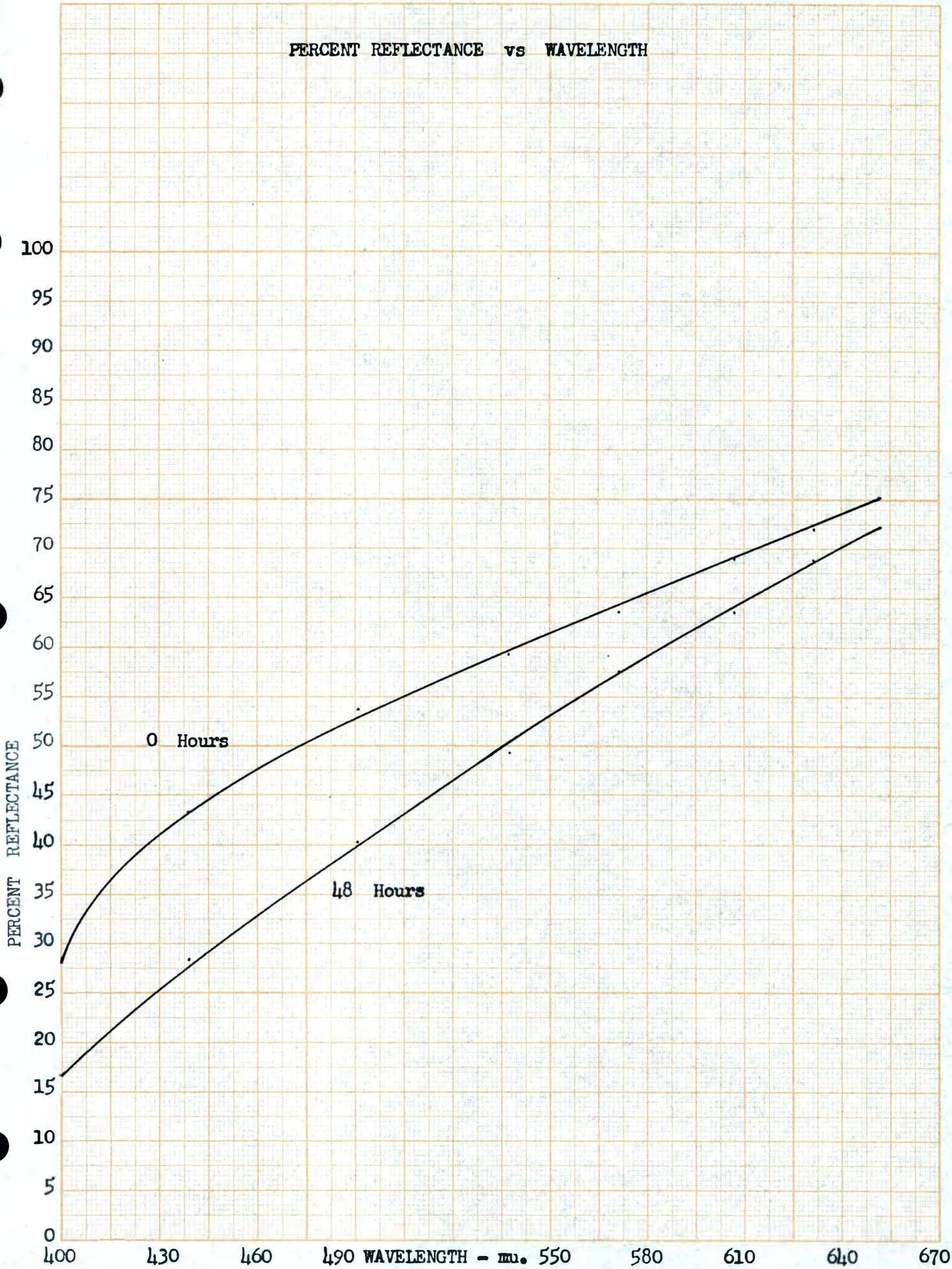
UNBLEACHED CONIFEROUS KRAFT



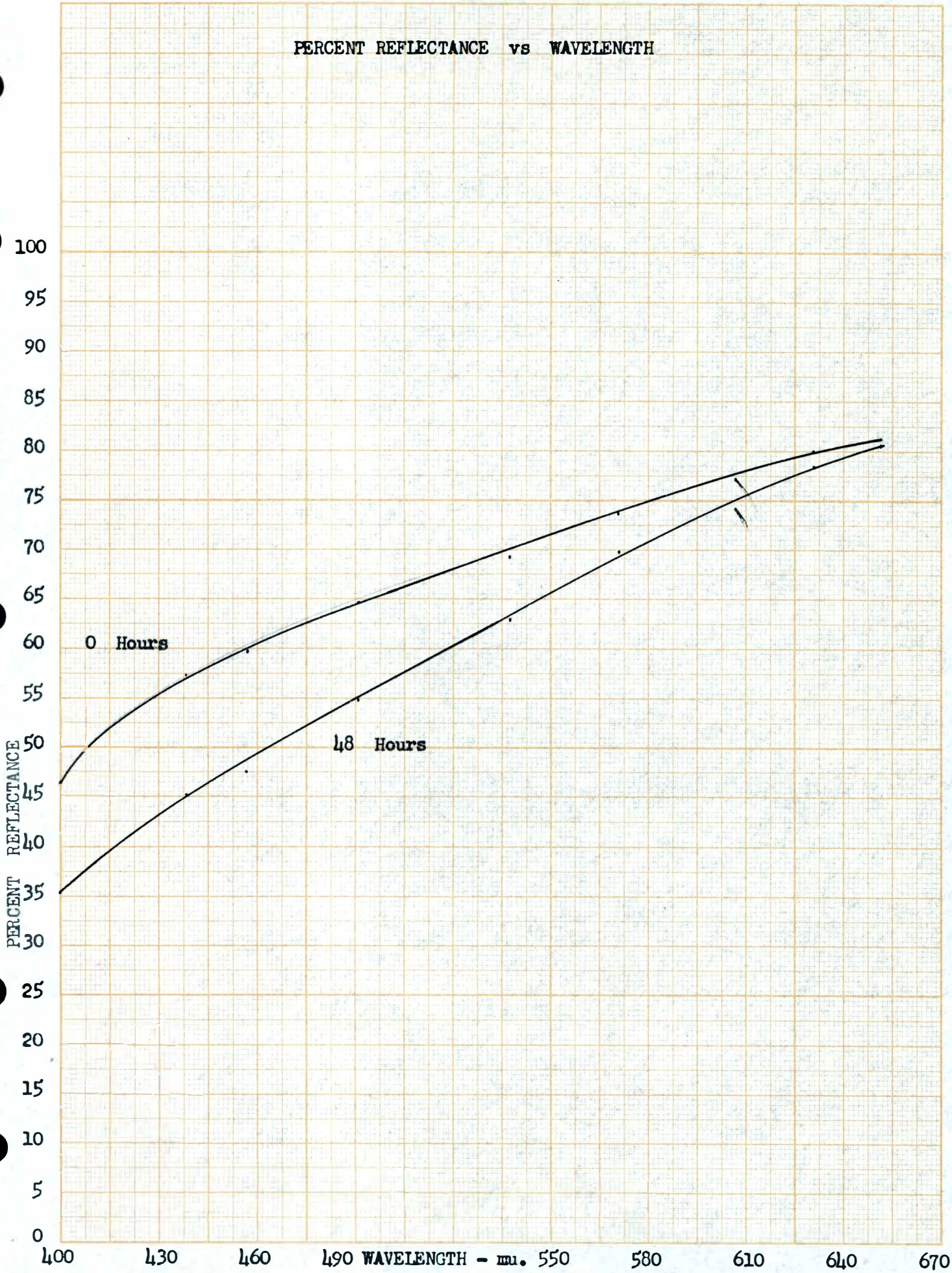
UNBLEACHED HARDWOOD SULPHITE



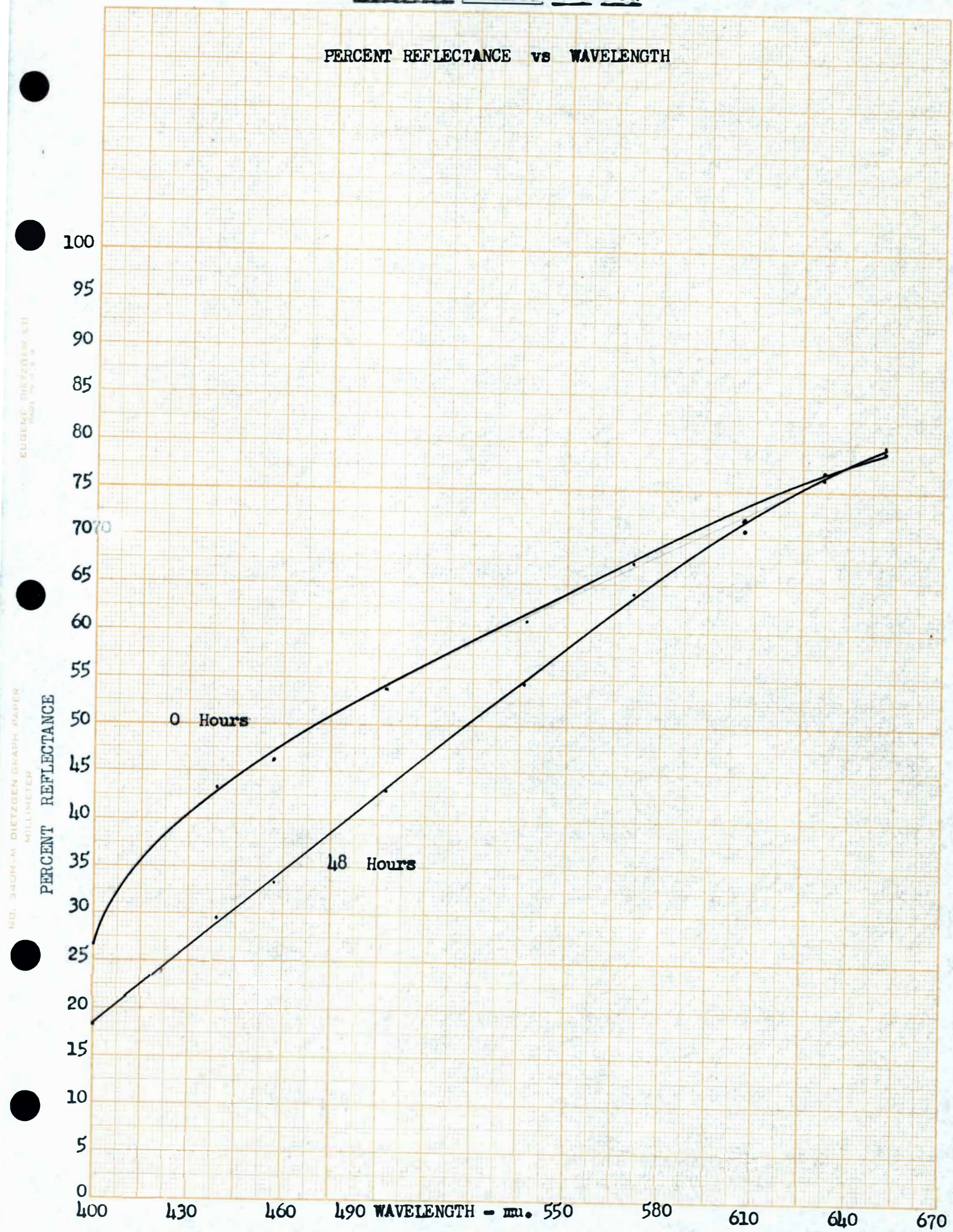
UNBLEACHED HARDWOOD N. S. S. C. (70% YIELD)



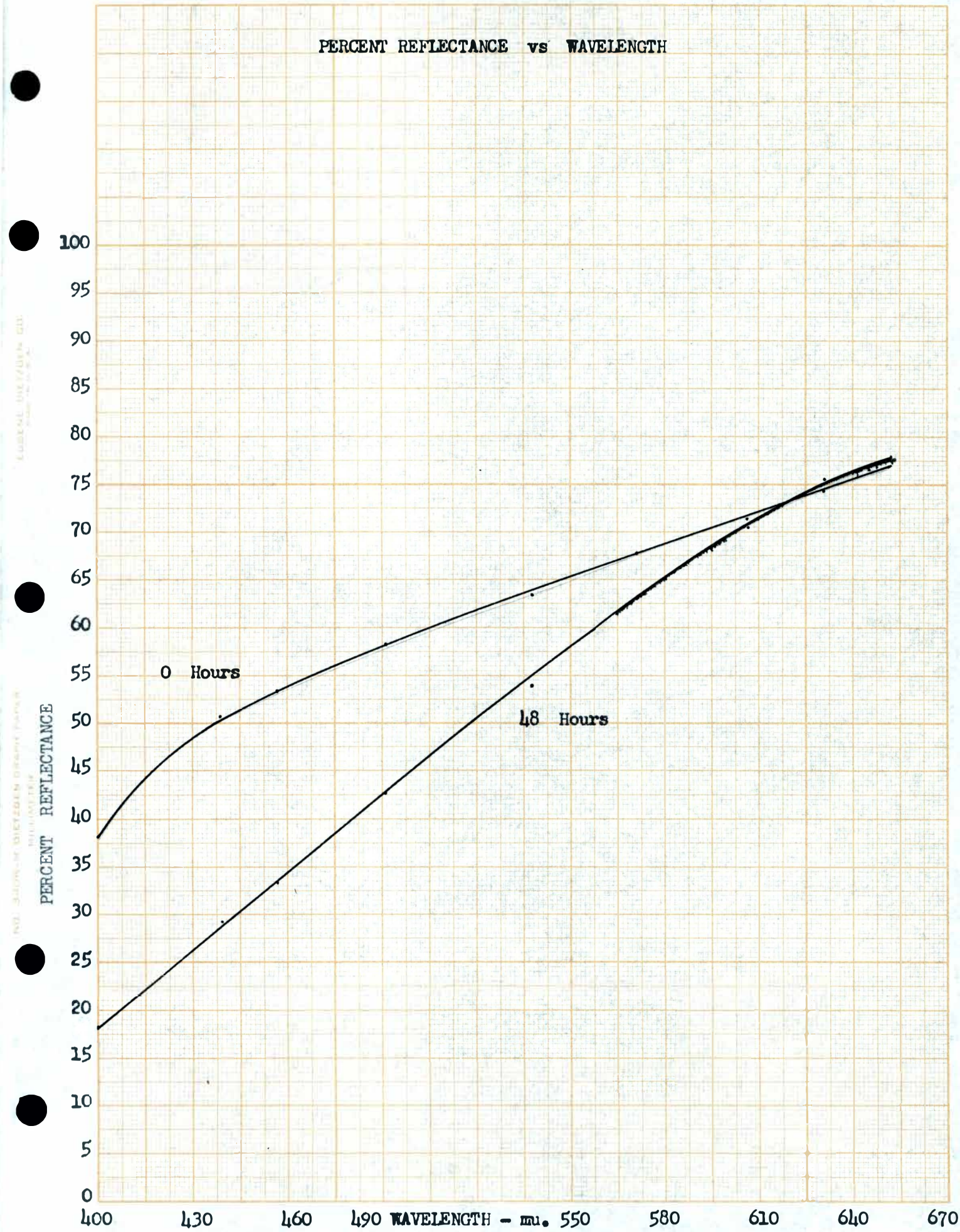
UNBLEACHED CONIFEROUS SULPHITE



UNBLEACHED HARDWOOD COLD SODA



UNBLEACHED HARDWOOD CHEMI-GROUNDWOOD



UNBLEACHED HARDWOOD N. S. S. C. (78% YIELD)