free fatty acids in the expeller oil were considerably higher than the free fatty acids shown by the seed analyses, while there was no unusual difference in the per cent of free fatty acids in the crude oil from the hydraulic mill, indicating that expelling may also cause an increase in free fatty acids and refining loss as well as color, especially when working high moisture seed.

SUMMARY

Both the expeller and hydraulic types of mills are used for crushing high moisture seed in the northeastern section of North Carolina. The quality of crude oil from the hydraulic mill is decidedly better than crude oil from the expeller mill, when the seed are comparable and as the moisture content of the seed increases the difference in quality of crude oil from the two types of mill is progressively greater in favor of the hydraulic mill.

The disintegration of cottonseed meats in the food chopper, used for the free fatty acid determination in cottonseed, and the expeller mill have a very similar effect on the color of the oil. Apparently the effect of expelling also causes an increase in free fatty acids and refining loss, especially when working high moisture seed.

THE COLOR AND SPECTRAL TRANSMITTANCE OF VEGETABLE OILS

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A PAPER PRESENTED AT THE 26TH ANNUAL MEETING OF THE AMERICAN OIL CHEMISTS' SOCIETY, AT MEMPHIS, MAY 23-24, 1935

ABSTRACT

A SPECTROPHOTOMETRIC analysis of 125 vegetable oils, 111 of which are from the cotton seed, has been made as a rational physical basis for the discussion and development of improved methods for the color grading of oils. The lightness and chromaticity of all the oils, and their spectral transmittance from 440 to 720 mμ, are indicated in tabular form. Consideration is given to some difficulties inherent in the color grading problem, arising chiefly from the independent variation of the concentrations of several different pigments present in the oils. Color grading in terms of the Lovibond glass standards is discussed along with other abridged methods of colorimetry suggested by the data.

CONTENTS

I. INTRODUCTION

The color of crude and refined vegetable oils is an important contributing factor in the determination of their market value. For many years the commercial color grading of oils has been based entirely on the Lovibond system of glass standards. Many difficulties in the use of this system have arisen in practice, involving inherent properties of the system itself or as the result of the methods of application. Attempts to substitute colorimetric methods based on other material color standards have likewise failed to provide a satisfactory solution to the problem.

As a rational physical basis for the analysis and discussion of the problem, and for the ultimate establishment of a more desirable procedure in color grading, an extensive investigation was undertaken of the spectral transmission and colorimetric properties of vegetable oils, covering a wide range of color variation in cottonseed oils from different geographical sources, and a more limited range of variation in vegetable oils of different plant origin.

The present paper gives the results of this study and a discussion of some difficulties inherent in the problem. Inasmuch as the color of these oils is at present universally expressed in terms of Lovibond glasses, this color system is also extensively employed in the present paper for comparison purposes.

II. SOURCE AND DESCRIPTION OF OILS

The vegetable oils included in this investigation were generously supplied by various manufacturers, dealers, and individuals interested in the work[3]. Information is generally unavailable on details of the methods of processing, the chemical composition, and the exact geographical origin of these oils. For purely colorimetric purposes, however, it is believed that collectively they are fairly representative of the majority of the edible vegetable oils of commerce, at least of the cottonseed oils. Such oils vary in color from a light greenish yellow

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[1] The spectrophotometric measurements of the oils were made between July 1915 and July 1920 under the immediate supervision of I. G. Priest with the coöperation and financial support of the Society of Cotton Products Analysts and the Interstate Cotton Seed Crushers Association. The author was employed by the above societies and detailed to the Bureau of Standards as research associate from July, 1915, to July, 1916. He was then appointed to the bureau staff. Reports involving some phases of this work have been published by Priest in the Cotton Oil Press, as follows: **3**, 86 (1919-20) No. 3; **3**, 37 (1919-20) No. 9; **4**, 95 (1920-21) No. 3.

*Publication approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[2] The author acknowledges the assistance of W. B. Emerson and M. K. Frehafer on some of the early spectrophotometric work. Throughout the recent analysis and preparation of data (1934-35) he is indebted to H. J. Keegan for assistance in computational work and to K. S. Gibson, D. B. Judd, and G. W. Haupt for much supplementary data supplied for the purposes of this paper. These data include all spectrophotometric or colorimetric data on the spectrum and the Lovibond glasses.

[3] The donors include Armour and Company, Harris Abattoir (Toronto), Procter and Gamble, Peet Bros., Globe Soap Co., Refuge Cotton Oil Co., Swift and Co., The Fort Worth Laboratories, Southern Cotton Oil Co., Corn Products Co., Phoenix Cotton Oil Co., Portsmouth Cotton Oil Co., Gunns Limited (Toronto), Capitol Refining Co., Armstrong Packing Co., Trinity Cotton Oil Co., American Cotton Oil Co., Falkenburg and Co., Empire Cotton Oil Co., Temple Cotton Oil Co., Independent Cotton Oil Co., Sea Island Cotton Oil Co., Magic City Oil Co., Felix Paquin, T. C. Law, F. N. Smalley, David Wesson, and P. S. Tilson.

through canary or amber yellow to brown or deep red, and contain varying proportions of several coloring matters commonly found in the tissues of plants.

The oils included in this work consist of 111 samples of refined cottonseed oils, designated in the tables and figures as groups A, B, D, E, and R, and 14 vegetable oils from other plant origin herein designated as group F. The latter group[4] includes samples of sesame, peanut, soybean, corn, rape, and olive oils. The A and B groups were received in 1915 and 1916 from 21 different refineries scattered widely throughout the country. The B group consists entirely of nearly prime wintered oils. The D group was collected in 1919 and 1920 from various individuals. The E group was obtained in 1920 through the Bureau of Chemistry and Soils of the U. S. Department of Agriculture from various sources in North Carolina, South Carolina, Georgia, Alabama, Tennessee, and Texas. The R group of refined oils was obtained in like manner along with samples of the crude oils from which the refinings were made.

III. SPECTRAL TRANSMISSION OF OILS

Complete information on the color of an oil may be derived when the transmission of light is specified for the oil at various wave lengths throughout the visible spectrum. Such measurements have been made for a 5¼ inch thickness of each oil and the results represented graphically by the curves in Figures 1 to 5. In these figures the solid-line curves represent cottonseed oils, and the broken-line curves the other oils of the F group. Oils of the A and B groups, in a ⅜ inch thickness, are represented in Figure 6. All data were obtained with the König-Martens spectrophotometer[5] at room temperature. There is no evidence of any change of importance in the transmittance of vegetable oils when the temperature is varied[6].

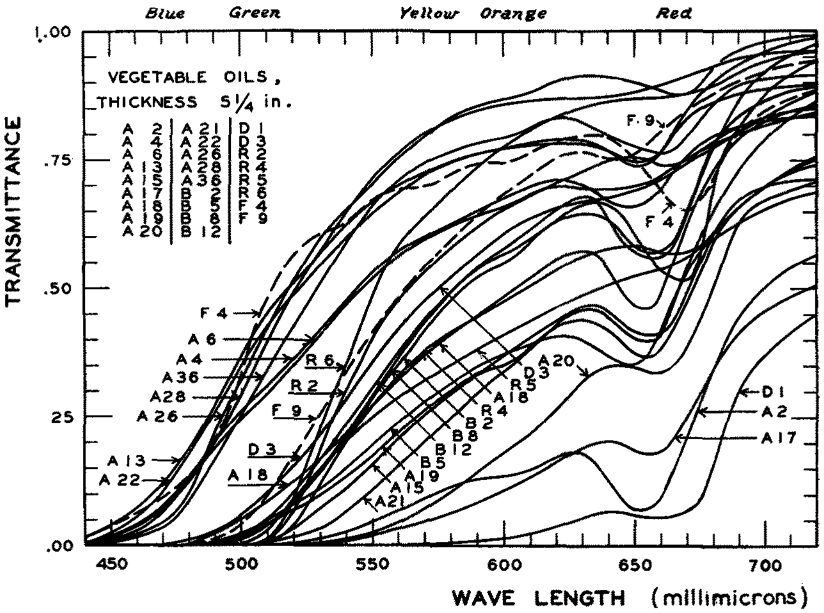

FIG. 1. SPECTRAL TRANSMITTANCE OF VEGETABLE OILS, THICKNESS 5¼"

The wide variation in form of the spectral transmittance curves for the various oils is proof of the presence of several different pigments in widely varying concentration. Little is known regarding the exact identity of these pigments. The well-defined absorption bands centered for most of the oils at wave lengths 670 and 610 mμ, and the similar bands shifted somewhat from these positions in a few cases (Fig. 5), show the presence undoubtedly of chlorophyll compounds, which, if present alone, would give the oils the characteristic green color of these materials in solution. It will be convenient to refer to these pigments collectively as the green group of coloring matters. It is evident also that one or more yellow pigments must be present having strong absorptive properties in the blue and violet regions of the spectrum, such as would result from the presence of one or several of the known yellow plant pigments. In addition some yellow, amber, or brown pigments must be

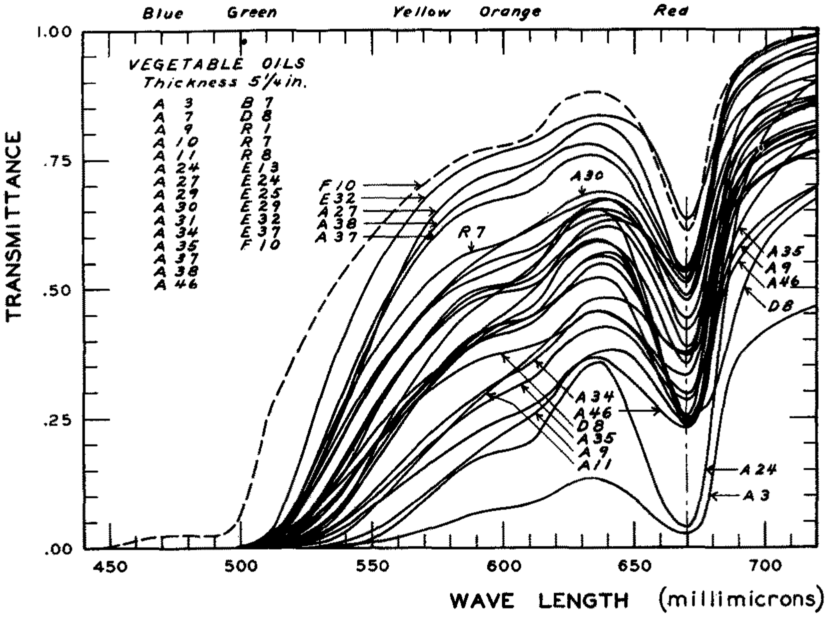

FIG. 2. SPECTRAL TRANSMITTANCE OF VEGETABLE OILS, THICKNESS 5¼"

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[4] Spectrophotometric data for oils F 10 to F 14 were taken from the work of Wesson, Cotton Oil Press 6, No. 5, September, 1922.

[5] B. S. Jour. Research 1, 793 (1928) R. P. 30. The arrangement of light source and auxiliary equipment for the spectrophotometric analysis of vegetable oils was not the same as described in this paper, but the method of measurement was essentially the same. Brass cells with glass end-plates were used to contain the oils. The measured transmission of these end-plates with a thin film of bleached oil between was found to be 0.892 for all wave lengths. Each measured transmission value of the cell filled with oil was divided by this number to give the transmittance of the oil itself, as represented in the figures and in Table 1.

[6] See Judd, B. S. Jr. Research, 1, 859, footnote 18 (1928).

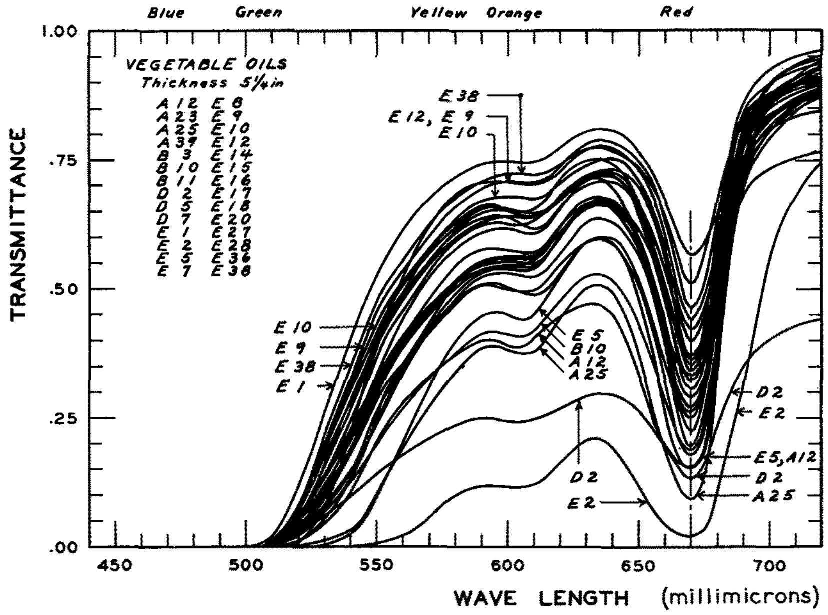

FIG. 3. SPECTRAL TRANSMISSION OF VEGETABLE OILS, THICKNESS 5¼"

present which are characterized by a more gradual increase in absorption from the red through the yellow and green to the blue. These yellow, amber, or brown materials will be denoted collectively as the brown group of pigments and are of considerable importance in determining the color of the oil in a 5¼ inch thickness. The general trend of the spectral transmissive properties for the brown group is represented by those curves in Figures 1 and 7 which exhibit little trace of the chlorophyll bands. Figure 7, lower part, shows the spectral transmittance of some crude cottonseed oils, herein denoted as the C group. During refining the brown pigments are removed in greater proportion than the green, as illustrated particularly by the transition from C 3 to R 3. Another factor possibly affecting the transmittance curves is the nearly non-selective scattering of light introduced by the residual turbidity of some of the oils. However, all noticeably turbid oils were filtered through absorbent cotton before measurements were made.

In Figures 1 to 4 the oils have been roughly classified in accordance with the form of their transmittance curves. All the oils show a strong absorption in the violet and blue regions of the spectrum which increases markedly with increasing yellowness or redness of the oils. Through the color transition we observe the existence of two principal spectral types. The "green" type (Fig. 4) is characterized by the presence chiefly of the green group of pigments with their sharp bands in the orange and red and lesser bands usually accompanying a sharp decrease in transmittance from the yellow into the green. The "brown" type (Fig. 1), on the other hand, shows no very pronounced absorption bands and exhibits a more gradual decrease in transmittance through the yellow and green. The two types of oils are observed to merge one into the other so that the observed color variations in a 5¼ inch thickness may be ascribed to a corresponding variation in the absolute and relative concentrations of the two groups of pigments. It is probable that for purely colorimetric purposes the color variation over the entire range of vegetable oils could be satisfactorily described in terms of the independent variation in concentration of two hypothetical pigments representative of the brown and green groups, respectively. This point is further discussed in Section VI.

In Figure 5 two small groups of oils are shown, each differing slightly from the oils in the preceding figures, and represented, respectively, by solid and broken lines. The solid-line curves represent cottonseed oils showing a definite displacement of the principal absorption band from the position at 670 mμ exhibited by the majority of all vegetable oils. This demonstrates the presence in general of more than one chlorophyll compound. These oils also contain a large proportion of the brown group of pigments. The broken-line curves in the figure represent samples of peanut, soybean, rape, and olive oils characterized here by the relatively high transmittance in the region about 580 mμ. These oils show the maximum proportion of the green pigments. They are the purest of the green spectral type and among the lightest of yellow oils included in this investigation. (See also Fig. 10.) In other oils of the predominantly green spectral type (Fig. 4) the transmittance maximum at 580 mμ is considerably reduced by the superposed characteristic transmit-

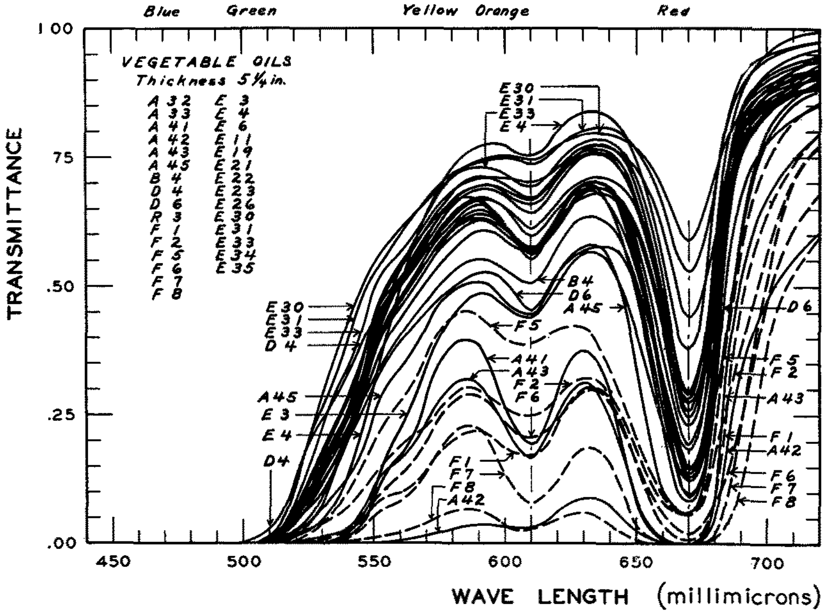

FIG. 4. SPECTRAL TRANSMITTANCE OF VEGETABLE OILS, THICKNESS 5¼"

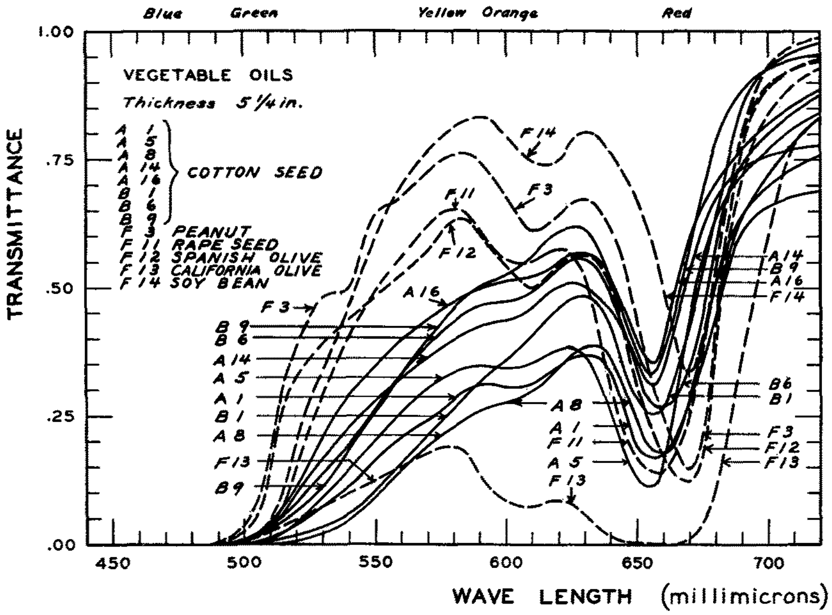

FIG. 5. SPECTRAL TRANSMITTANCE OF VEGETABLE OILS, THICKNESS 5¼"

tance of the brown pigments present. It may be noted that one oil, F 11, combines both spectral characteristics exhibited in Figure 5, namely, the high transmittance maximum at 580 mμ and the displacement of the principal cholorophyll band.

The classification of oils into two principal spectral types is further illustrated by the curves in Figure 6 for a ⅜ inch thickness. The dash-dot curves represent all oils of groups A and B included in Fig. 1, along with oils A 1, B 6, and B 9 of Figure 5. They are the purest A and B representatives of the brown spectral type. Among the remaining oils, the strong absorption in the blue corresponds to the sharp cut-off near 510 mμ as observed in Figures 3 and 4.

A comparison of the solid and broken-line curves in Figures 1 to 5 shows the essential sameness in spectral transmissive properties between cottonseed and other vegetable oils herein examined. For each of the other vegetable oils there is a cottonseed oil not differing essentially in spectral type. This fact has been pointed out by Priest[7] for one sample of soybean oil, and is further illustrated by Wesson[8] for peanut, rape, olive, and cocoanut oil. The most significant difference herein exhibited between cottonseed oils and the rape, soybean, sesame, and olive oils is the relatively higher transmittance of the latter group near 580 mμ as compared with that near 630 mμ. This follows from the smaller proportion of brown pigment materials. Hence, we may regard the problem of color grading over the entire range of cottonseed oils as practically encompassing that for all vegetable oils.

IV. COLORIMETRIC PROPERTIES

Having the spectral transmittance of an oil (or Lovibond glass combination) we may proceed by purely analytical or graphical methods to derive[9] various colorimetric specifications, with reference to a standard illuminant, observer, and

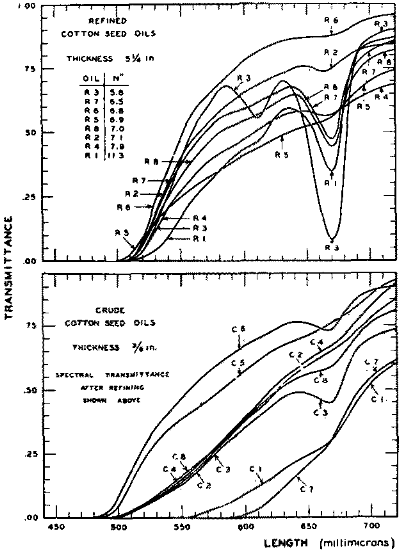

FIG. 7. SPECTRAL TRANSMITTANCE OF CRUDE COTTONSEED OILS AND REFININGS FROM SAME, SHOWING THE EFFECT OF THE REFINING PROCESS ON THE SELECTIVE REMOVAL OF PIGMENT COMPONENTS IN THE OILS, AND THE REDUCTION IN TOTAL PIGMENT CONTENT. THE THICKNESS RATIO OF CRUDE TO REFINED OILS, FOUND NECESSARY TO OBTAIN COMPARABLE TRANSMITTANCE DATA, SHOWS (BY BEER'S LAW) THAT THE REDUCTION IN TOTAL PIGMENT CONTENT IS ROUGHLY 93 PER CENT.

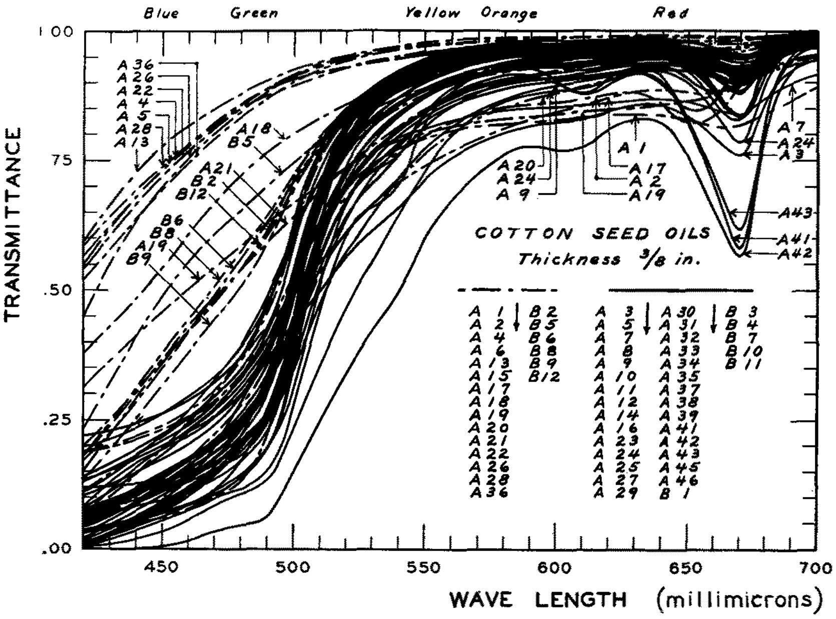

FIG. 6. SPECTRAL TRANSMITTANCE OF COTTONSEED OILS, THICKNESS ⅜"

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[7] Cotton Oil Press, January, 1920.

[8] Cotton Oil Press, 6, No. 5. September, 1922. These spectrophotometric data on the peanut, rape, and olive oils are reproduced in the present paper.

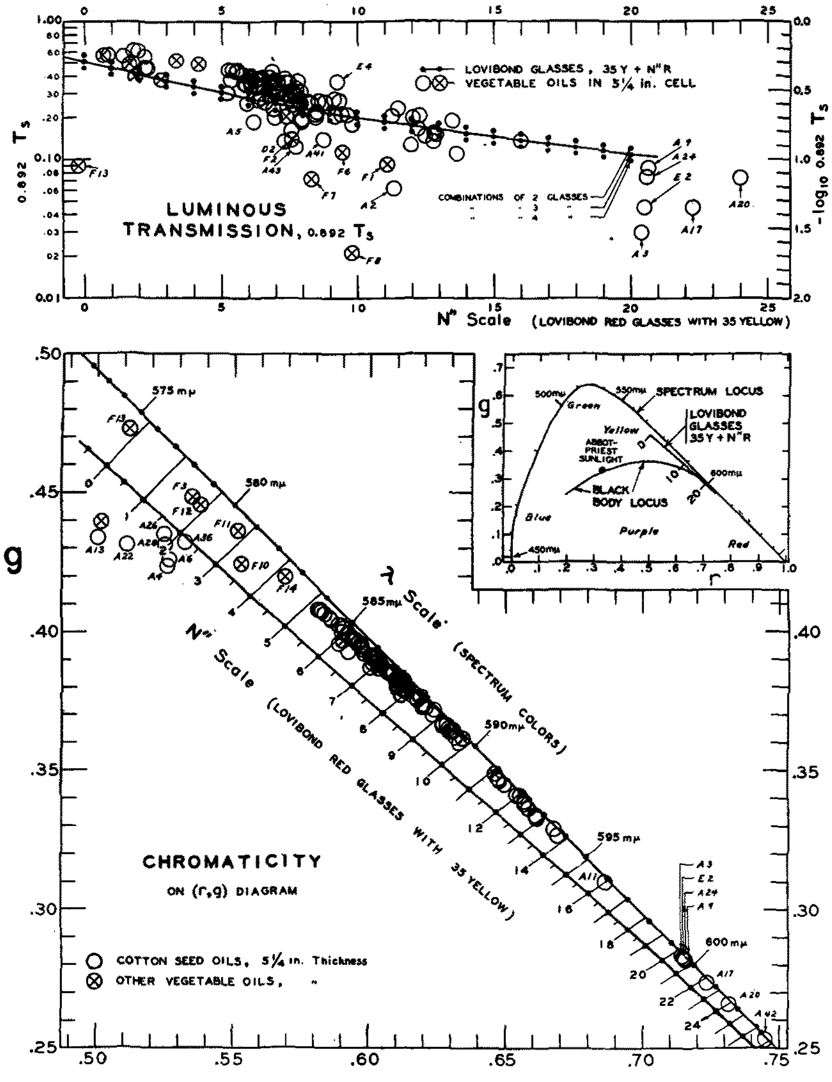

FIG. 8. COLORIMETRIC PROPERTIES OF VEGETABLE OILS.

coordinate system. In the present paper the standard illuminant is Abbott-Priest sun[10], which serves also as the basic stimulus[11] for a trilinear coordinate system[12]. The standard observer and coordinate system are defined by the (extrapolated) O. S. A. visual response functions[13]. These reference conditions are the same as have been employed in all standardization work on Lovibond glasses at the National Bureau of Standards[14]

Assuming that a 5¼ inches column of oil is illuminated by light from the standard illuminant, the luminous transmittance T_s and the trilinear coordinates (r, g, b) have been determined from the given properties of the source and observer and the measured values of spectral transmittance. These quantities are listed in columns 3, 4, 5, and 6 of Table 1. They specify, respectively, the purely luminous and chromatic aspects of the vegetable oil colors (lightness and chromaticity, respectively). Inasmuch as the trilinear coordinates sum to unity by definition, any two of them may be used in a graphical representation of chromaticity. This is done on the (r, g) diagram

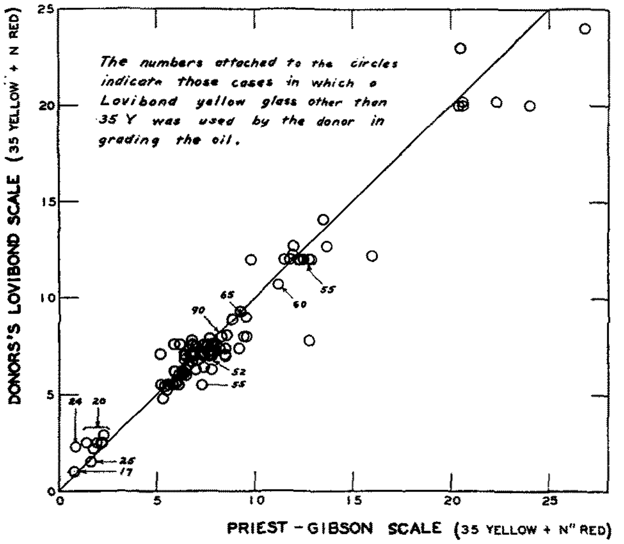

FIG. 9. COMPARISON OF LOVIBOND GRADES ASSIGNED BY DONORS OF OILS WITH THOSE DERIVED IN THE PRESENT INVESTIGATION.

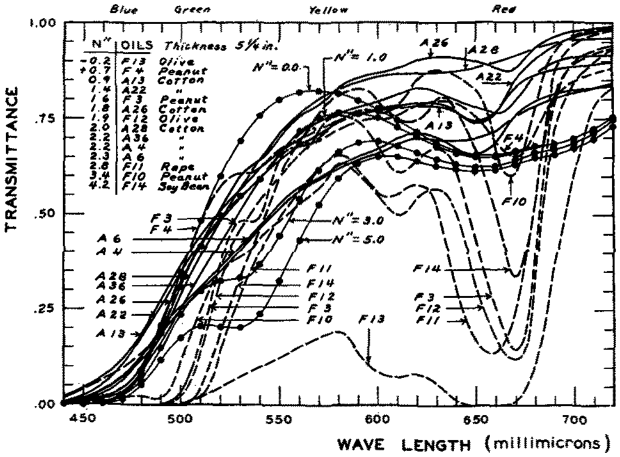

FIG. 10. SPECTRAL TRANSMISSIVE PROPERTIES OF OILS AND LOVIBOND GLASS COMBINATIONS (FILLED CIRCLES) IN THE RANGE OF N" BETWEEN 0 AND 5.

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[9] For methods of computing colorimetric properties from spectral transmittance and other data, see J. Opt. Soc. Am. and Rev. Sci. Inst., **6**, 527 (1922), J. Opt. Soc. Am., **23**, 359 (1933).

[10] J. Opt. Soc. Am. and Rev. Sci. Inst., **12**, 479 (1926).

[11] J. Guild. On the Fixed Points of a Colorimetric System. Discussion by Priest, Trans. Opt. Soc., **32**, 25 (1930-31).

[12] J. Opt. Soc. Am. and Rev. Sci. Inst., **9**, 506 (1924).

[13] J. Opt. Soc. Am. and Rev. Sci. Inst., **10**, 230 (1925).

[14] B.S. J. Research **13**, 433 (1934); RP 718. Also, Oil and Soap, **11**, 246 (1934). This paper contains complete references to previous work.

TABLE 1.—COLORIMETRIC PROPERTIES OF VEGETABLE OILS FOR A THICKNESS OF 5¼ INCHES.

N.B.S. Lab. No.	Kind of Oil or Source	Sunlight Transmittance	Trilinear Coordinates			Lovibond Grade by Donor		Lovibond Grade by N.B.S. on 35Y basis	Wave Length	Spectral Transmittance shown in	
		T_s	r	g	b	Y	R	R	λ	Fig.	Fig.
1	2	3	4	5	6	7		8	9	10	11
A 1	Refined Cottonseed Oils, Received June, 1915, from Various Manufacturers.	0.183	0.6093	0.3822	0.0085	35	7.6	7.6	587.0	5	13
A 2		.070	.6477	.3461	.0062	35	12.0	11.3	591.3	1	15
A 3		.034	.7140	.2832	.0028	35	20.0	20.4	599.5	2	16
A 4		.521	.5262	.4260	.0477	20	2.5	2.2	579.8	1	10
A 5		.213	.5934	.3976	.0090	35	7.6	6.2	585.3	5	12
A 6		.514	.5255	.4236	.0509	20	2.9	2.3	579.9	1	10
A 7		.249	.6195	.3726	.0079	35	7.4	8.5	588.1	2	14
A 8		.142	.6540	.3409	.0051	35	12.2	12.0	592.0	5	15
A 9		.098	.7153	.2818	.0029	35	20.2	20.6	599.7	2	16
A 10		.234	.6269	.3659	.0072	35	7.4	9.2	588.9	2	14
A 11		.154	.6863	.3098	.0040	35	12.2	16.0	596.1	2	16
A 12		.227	.6200	.3736	.0064	35	7.0	8.5	588.1	3	14
A 13		.640	.5002	.4339	.0659	24	2.3	0.9	578.3	1	10
A 14		.286	.5894	.3996	.0110	35	7.6	5.9	585.0	5	11
A 15		.203	.6330	.3596	.0075	35	12.0	9.8	589.6	1	14
A 16		.238	.5809	.4078	.0113	35	7.1	5.2	584.1	5	11
A 17		.504	.7233	.2736	.0032	35	20.2	22.3	600.7	1	16
A 18		.305	.5919	.3928	.0153	35	7.1	6.4	585.5	1	12
A 19		.213	.6116	.3771	.0113	35	7.6	7.9	587.5	1	13
A 20		.082	.7314	.2657	.0029	35	20.0	24.0	601.7	1	16
A 21		.170	.6612	.3326	.0062	35	12.0	12.9	592.9	1	15
A 22		.629	.5108	.4314	.0578	20	2.5	1.4	578.3	1	10
A 23		.404	.6010	.3908	.0083	35	7.8	6.8	586.1	3	12
A 24		.084	.7151	.2821	.0028	35	20.0	20.6	599.7	2	16
A 25		.188	.6569	.3388	.0043	35	12.0	12.2	592.3	3	15
A 26		.690	.5244	.4351	.0405	20	2.2	1.8	579.0	1	10
A 27		.434	.6065	.3855	.0080	35	7.1	7.3	586.7	2	13
A 28		.682	.5246	.4313	.0441	20	2.5	2.0	579.3	1	10
A 29		.262	.6496	.3449	.0055	35	12.0	11.5	591.5	2	15
A 30		.346	.6128	.3789	.0083	35	7.2	7.9	587.4	2	13
A 31		.234	.6568	.3379	.0053	35	12.0	12.3	592.3	2	15
A 32		.405	.6075	.3852	.0073	35	7.6	7.4	586.8	4	13
A 33		.352	.6100	.3827	.0073	35	7.6	7.6	587.0	4	13
A 34		.166	.6583	.3362	.0055	35	12.0	12.5	592.5	2	15
A 35		.151	.6609	.3337	.0054	55	12.0	12.8	592.8	2	15
A 36		.624	.5320	.4323	.0358	20	2.5	2.2	579.7	1	10
A 37		.417	.6023	.3892	.0085	35	7.1	6.9	586.3	2	12
A 38		.437	.5999	.3912	.0089	35	7.1	6.8	586.0	2	12
A 39		.378	.6024	.3893	.0083	35	7.1	7.0	586.3	3	12, 13
A 41		.158	.6238	.3716	.0046	35	8.9	8.8	588.4	4	14
A 42		.118	.7448	.2531	.0021	35	24.0	26.8	603.2	4	16
A 43		.139	.6124	.3821	.0055	35	7.9	7.7	587.2	4	13
A 45		.279	.6107	.3825	.0068	35	7.6	7.6	587.1	4	13
A 46		.123	.6687	.3263	.0050	35	12.7	13.7	593.8	2	16
B 1	Prime Winter Cottonseed Oils	.175	.6609	.3334	.0057	35	7.8	12.8	592.9	5	15
B 2		.325	.6100	.3803	.0097	35	7.0	7.7	587.2	1	13
B 3		.324	.6094	.3827	.0079	35	7.2	7.6	587.0	3	13
B 4		.330	.6004	.3913	.0084	35	6.7	6.8	586.1	4	12
B 5		.225	.5999	.3871	.0131	35	6.3	7.0	586.3	1	12
B 6		.289	.5976	.3921	.0104	35	6.5	6.6	585.9	5	12, 13
B 7		.292	.6232	.3698	.0070	45	7.2	8.8	588.5	2	14
B 8		.337	.6096	.3805	.0099	35	7.0	7.7	587.2	1	13
B 9		.301	.6118	.3792	.0090	35	6.3	7.8	587.4	5	13
B 10		.239	.6194	.3732	.0074	35	7.1	8.5	588.1	3	14
B 11		.323	.6117	.3806	.0077	35	7.3	7.8	587.3	3	13
B 12		.341	.6029	.3867	.0105	35	6.8	7.1	586.4	1	13
D 1	Cottonseed Oils	.009	.8388	.1612	.0000	..	...	...	.....	1	16
D 2		.151	.6063	.3854	.0084	55	5.5	7.3	586.7	3	13
D 3		.386	.5884	.3957	.0159	35	5.5	6.1	585.2	1	12
D 4		.422	.5822	.4072	.0106	35	4.8	5.3	584.2	4	11
D 5		.365	.6115	.3810	.0075	35	7.1	7.7	587.2	3	13
D 6		.314	.5967	.3948	.0085	35	6.0	6.5	585.7	4	12
D 7		.288	.6176	.3753	.0071	..	...	8.3	587.9	3	14
D 8		.220	.6135	.3783	.0082	35	6.2	8.0	587.5	2	13, 14
E 1	Ga.	.493	.5834	.4065	.0101	35	5.4	5.4	584.3	3	11
E 2	Tenn.	.050	.7146	.2826	.0028	35	23.0	20.5	599.6	3	16
E 3	Ala.	.224	.6554	.3407	.0039	35	12.7	12.0	592.1	4	15
E 4	Ala.	.410	.6283	.3661	.0057	35	9.3	9.2	589.0	4	14
E 5	Ala.	.214	.6675	.3287	.0038	35	14.1	13.5	593.6	3	16
E 6	N. C.	.426	.5945	.3971	.0085	35	6.2	6.3	585.4	4	12
E 7	Ala.	.299	.6290	.3647	.0063	..	...	9.4	589.1	3	14
E 8	Ala.	.308	.6269	.3667	.0064	..	...	9.2	588.9	3	14
E 9	S. C.	.439	.5963	.3949	.0088	35	6.1	6.4	585.6	3	12
E 10	Ga.	.421	.5954	.3958	.0088	..	...	6.4	585.5	3	12
E 11	Ga.	.368	.6030	.3894	.0076	35	7.5	7.0	586.3	4	12, 13
E 12	S. C.	.411	.6128	.3806	.0066	35	7.5	7.8	587.3	3	13
E 13	S. C.	.238	.6316	.3617	.0067	35	8.0	9.6	589.4	2	14
E 14	N. C.	.297	.6207	.3725	.0068	35	8.1	8.6	588.2	3	14
E 15	Tex.	.392	.6003	.3914	.0084	35	7.6	6.8	586.1	3	12
E 16	Ala.	.336	.6072	.3847	.0081	..	...	7.4	586.8	3	13
E 17	N. C.	.416	.5916	.3994	.0091	35	5.7	6.0	585.2	3	12
E 18	N. C.	.396	.6002	.3915	.0083	35	7.5	6.8	586.0	3	12
E 19	Ga.	.406	.6018	.3903	.0080	35	7.0	6.9	586.2	4	12
E 20	S. C.	.396	.5944	.3969	.0088	35	6.0	6.3	585.4	3	12
E 21	N. C.	.429	.5965	.3952	.0083	35	7.0	6.4	585.6	4	12
E 22	Ga.	.374	.5946	.3970	.0085	35	6.0	6.3	585.4	4	12
E 23	S. C.	.408	.5917	.3995	.0089	35	5.6	6.0	585.1	4	12
E 24	Ala.	.336	.6073	.3844	.0083	35	6.4	7.4	586.8	2	13
E 25	Ala.	.295	.6163	.3764	.0074	35	7.4	8.2	587.7	2	14

TABLE 1.—(Continued)

N.B.S. Lab. No.	Kind of Oil or Source	Sunlight Transmittance	Trilinear Coordinates			Lovibond Grade			Wave Length	Spectral Transmittance shown in	
						by Donor		by N.B.S. on 35Y basis			
		T_s	r	g	b	Y	R	R	λ	Fig.	Fig.
1	2	3	4	5	6	7		8	9	10	11
E 26	Ga.	.390	.5903	.4014	.0083	35	6.2	5.9	585.0	4	11
E 27	Ga.	.337	.6038	.3879	.0083	..	...	7.1	586.4	3	13
E 28	Ga.	.339	.6113	.3814	.0073	35	7.2	7.7	587.2	3	13
E 29	S. C.	.240	.6295	.3637	.0068	35	8.0	9.4	589.2	2	14
E 30	N. C.	.496	.5818	.4080	.0102	35	5.5	5.2	584.1	4	11
E 31	Ga.	.486	.5852	.4050	.0098	35	5.2	5.5	584.5	4	11
E 32	S. C.	.502	.5856	.4043	.0102	35	5.5	5.6	584.5	2	11
E 33	N. C.	.460	.5882	.4025	.0093	35	5.5	5.8	584.8	4	11
E 34	Tex.	.380	.5957	.3960	.0083	35	6.8	6.4	585.5	4	12
E 35	N. C.	.369	.6028	.3898	.0075	35	7.2	6.9	586.3	4	12
E 36	Tex.	.298	.6096	.3827	.0077	35	7.5	7.6	587.0	3	13
E 37	Ga.	.287	.6135	.3790	.0075	35	7.6	7.9	587.4	2	13
E 38	Ala.	.454	.5918	.3993	.0090	35	6.0	6.1	585.2	3	12
R 1	Cottonseed Oils	.232	.6473	.3468	.0059	..	...	11.3	591.2	2	15
R 2		.405	.6032	.3880	.0088	..	...	7.0	586.4	1	13
R 3		.398	.5896	.4022	.0082	..	...	5.8	584.9	4	11
R 4		.289	.6124	.3794	.0082	..	...	7.9	587.4	1	13
R 5		.261	.6008	.3887	.0106	..	...	6.9	586.2	1	12
R 6		.484	.6009	.3902	.0089	..	...	6.8	586.1	1	12
R 7		.376	.5970	.3938	.0092	..	...	6.5	585.7	2	12
R 8		.340	.6025	.3887	.0088	..	...	7.0	586.3	2	12, 13
F 1	Sesame	.103	.6463	.3486	.0051	60	10.7	11.1	591.0	4	15
F 2	Sesame	.157	.6102	.3828	.0070	52	7.0	7.6	587.0	4	13
F 3	Peanut	.544	.5347	.4485	.0168	25	1.5	1.6	578.8	5	10
F 4	Peanut	.638	.5015	.4396	.0589	17	1.0	0.7	577.0	1	10
F 5	Soybean	.230	.6083	.3854	.0063	35	7.0	7.4	586.8	4	13
F 6	Soybean	.128	.6308	.3643	.0049	65	9.0	9.5	589.2	4	14
F 7	Soybean	.082	.6189	.3763	.0048	90	8.0	8.3	587.9	4	14
F 8	Soybean	.024	.6344	.3613	.0042	..	...	9.8	589.6	4	14
F 9	Corn	.439	.5899	.3968	.0133	..	...	6.1	585.2	1	12
F 10	Peanut	.584	.5525	.4245	.0230	..	...	3.4	581.5	2	10
F 11	Rape	.423	.5514	.4364	.0122	..	...	2.8	580.7	5	10
F 12	S. Olive	.442	.5377	.4455	.0168	..	...	1.9	579.2	5	10
F 13	C. Olive	.100	.5120	.4729	.0151	..	...	—0.2	575.1	5	10
F 14	Soybean	.550	.5687	.4198	.0115	..	...	4.2	582.7	5	10

of Figure 8, which shows the Lovibond 35Y + N″R locus[15] and a part of the spectrum (λ) locus. The relation of chromaticities on the 35Y + N″R scale for the complete spectrum locus, the black-body locus, and the standard illuminant, is shown on the small-scale (r, g) diagram in the figure.

The chromaticities of all the oils have also been evaluated on the one-dimensional (35Y + N″R) and λ scales by projection of points representing the oils parallel to the system of crosslines drawn in Figure 8, and then reading the projected points from the given scales. The results are recorded in columns 8 and 9 of Table 1. To a sufficient approximation for present purposes the analytical and graphical procedure[16] involved is equivalent to the establishment of a nearest chromaticity setting between an oil and the series of Lovibond glass combinations (or the series of spectrum colors), when compared in a two-part photometric

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[15] B.S. J. Research 13, 433 (1934); R.P. 718. Also, Oil and Soap, 11, 246 (1934). The N″R scale is based on the new derivation of unit red in the Lovibond system, yielding a consistent additive scale when combined with 35 yellow.

[16] To determine the directions of the projection lines, the 35 Y + N″R and λ loci were first transferred by a prescribed transformation of coordinates from the O.S.A. colorimetric system of Figure 8 to the uniform-scale system devised by Judd (J. Research NBS, 14, 41 (1935) RP 756, or J. Opt. Soc. Am. 25, 24 (1935). In this new system, the nearest chromaticity match to be found for a given color out of any series of colors (such as the 35Y + N″R series, or the series of spectrum colors) is determined by drawing the shortest line (the perpendicular) from the point representing the given color to the locus representing the series. Accordingly, sets of perpendiculars were drawn both to the 35Y + N″R locus and to the spectrum locus; but since these loci in the uniform-scale system are nearly straight, parallel lines, these sets of perpendiculars are almost identical. Hence, one set will serve to determine both N″ and λ values of any color represented by points in the neighborhood of these loci. The series of cross-lines shown in Figure 8 corresponds to this set of perpendiculars.

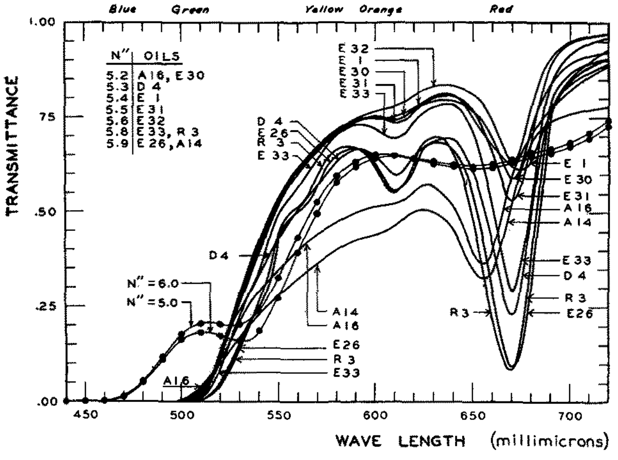

FIG. 11. SPECTRAL TRANSMISSIVE PROPERTIES OF OILS AND LOVIBOND GLASS COMBINATIONS (FILLED CIRCLES) IN THE RANGE OF N″ BETWEEN 5 AND 6.

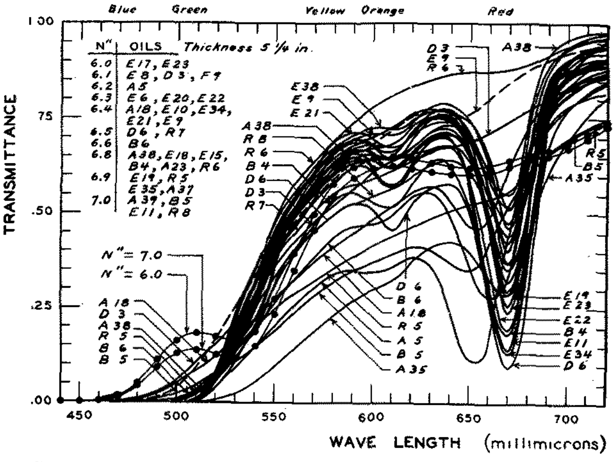

FIG. 12. SPECTRAL TRANSMISSIVE PROPERTIES OF OILS AND LOVIBOND GLASS COMBINATIONS (FILLED CIRCLES) IN THE RANGE OF N″ BETWEEN 6 AND 7.

field under the standard condition of illuminant and observer herein prescribed.

A comparison is made in Figure 9 between the N″ values herein assigned to the oils and the N values submitted by donors of the oils. (Column 7, Table1.) The spread of values about the straight line shows that any difference between the two chromaticity scales is negligible compared with erraticisms in the assignment of grades.

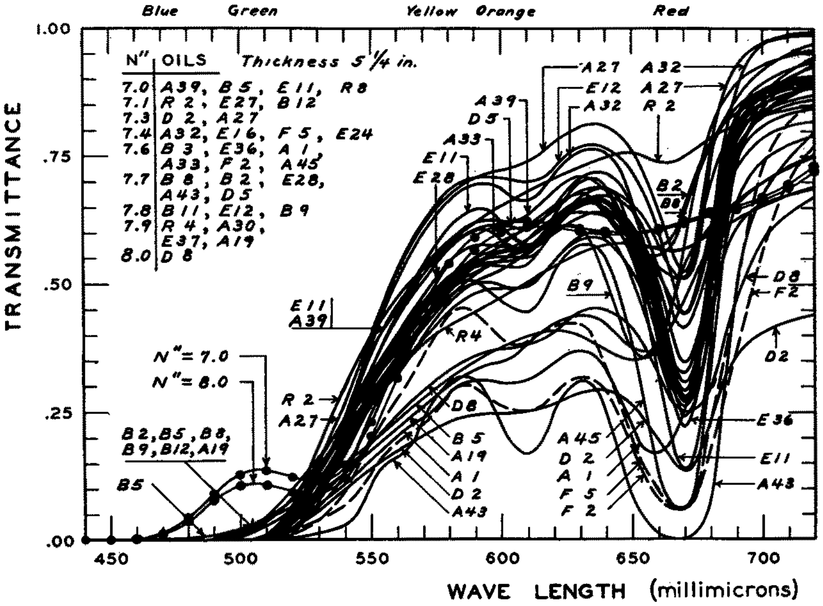

FIG. 13. SPECTRAL TRANSMISSIVE PROPERTIES OF OILS AND LOVIBOND GLASS COMBINATIONS (FILLED CIRCLES) IN THE RANGE OF N″ BETWEEN 7 AND 8.

The luminous transmissions[17] of the cell-plus-oil and Lovibond glass combinations are compared in the upper part of Figure 8. Values for combinations of 2, 3, and 4 glasses are shown.

In Figures 10 to 16 the spectral transmittance curves for all the oils are replotted in a new classification, this time in accordance with their color grade. Again solid lines represent cottonseed oils and broken lines the other vegetable oils. The filled circles show the course of the spectral transmittance[18] curves for Lovibond glass combinations on the scale of 35 yellow + N″ red. In each figure, the assigned color grades of the group of oils therein represented lie between the N″ values indicated in the figure.

V. DISCUSSION OF DATA ON OILS AND LOVIBOND GLASSES

The wide variation in spectral transmissive properties within the group of vegetable oils is illustrated by the classification in Figures 1 to 5. A like variation between oils of nearly the same chromaticity is also illustrated in Figures 10 to 16, along with the divergence of the oils, taken collectively, from the Lovibond glass combinations in the same chromaticity range. These variations in spectral transmissive properties are all translated into colorimetric terms and indicated by the spread of points in the upper and lower diagrams of Figure 8.

The regular variation in spectral transmittance, lightness, and chromaticity for the sequence of color standards along the one-dimensional N″ scale follows from the regular variation in concentration of coloring material in the glass combinations. On the constant yellow basis, this variation resides solely in one component (red) of a two-component system (yellow + red). The lateral spread of points representing lightness and chromaticity of the vegetable oils follows from the irregular variations in form of the spectral transmittance curves, and, assuming for simplicity that these variations may be ascribed likewise to variations in a two-component system (hypothetical brown and green pigments), we find the important difference exhibited in this case that the relative and absolute concentrations of the oil-pigment components may vary independently of one another. It is implied, therefore, that no one-dimensional chromaticity scale is possible on which all vegetable oils or all cottonseed oils can be accurately represented.

It may be noted at this point that the situation in this respect might be improved somewhat if it were feasible to modify or control the refining processes so as to confine

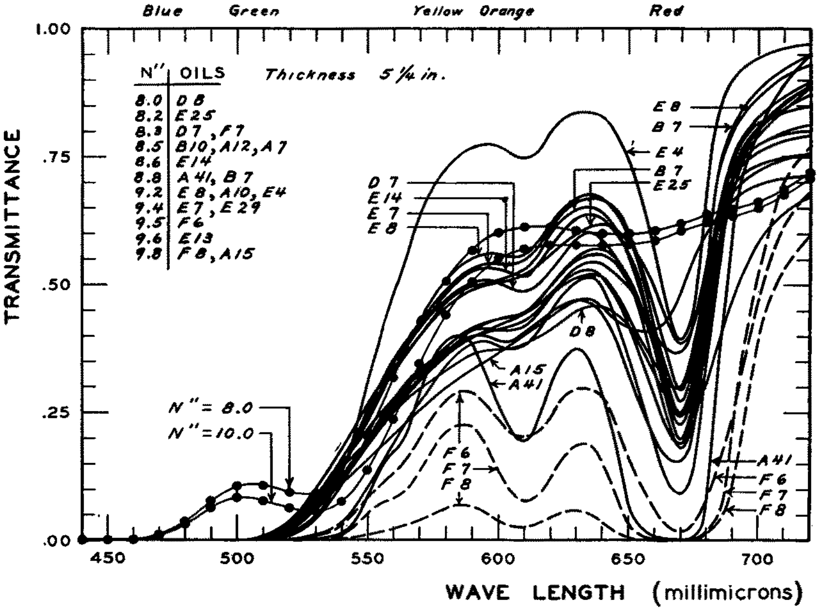

FIG. 14. SPECTRAL TRANSMISSIVE PROPERTIES OF OILS AND LOVIBOND GLASS COMBINATIONS (FILLED CIRCLES) IN THE RANGE OF

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[17] Luminous transmissions differ from the luminous transmittances in column 3 of Table 1 by a factor 0.892, as explained in footnote 5. Luminous transmissions given in Figure 8 for a combination of two Lovibond glasses are multiplied by 0.901 and $(0.901)^2$ respectively, to obtain the transmissions for a combination of three or four glasses. Multiple reflections between glass surfaces are disregarded. The number 0.901 is the transmission of a single clear glass.

[18] Given spectral transmission curves for combinations of two glasses were divided by $(0.901)^2$ to derive the values of transmittance. When transmission curves for integral values of N″ were not available, they were found for present purposes by interpolation.

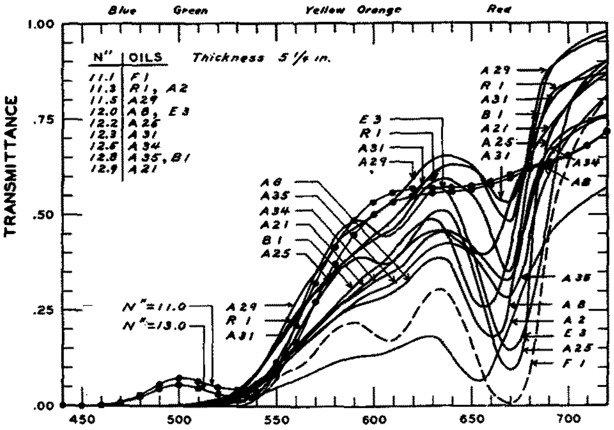

FIG. 15. SPECTRAL TRANSMISSIVE PROPERTIES OF OILS AND LOVIBOND GLASS COMBINATIONS (FILLED CIRCLES) IN THE RANGE OF N″ BETWEEN 11 AND 12.

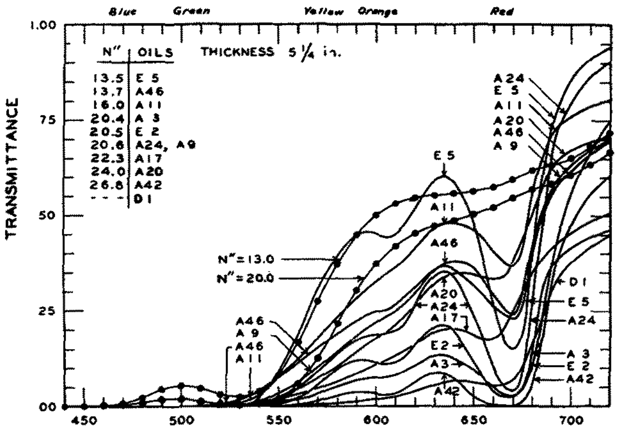

FIG. 16. SPECTRAL TRANSMISSIVE PROPERTIES OF OILS AND LOVIBOND GLASS COMBINATIONS (FILLED CIRCLES) IN THE RANGE OF N″ BETWEEN 13 AND 20.

the variation in pigment composition more nearly to one group of pigments, thus approaching the simpler condition of a one-component system. Inasmuch as information is unavailable on methods and conditions employed in the processing of these oils, no conclusive evidence on this matter can be gleaned from the present investigation. It is observed, however, that in refining the crude oils represented in Figure 7 the brown pigments are more selectively removed than the green, when the latter are present in notable proportion. A continuation of this process would yield oils of a light-yellow or olive-oil hue, as illustrated in Figures 5 and 10 by the broken-line curves, and in Figure 8 (lower part) by the crossed circles for oils F 10 to F 14. Oil F 13, having perhaps the highest proportion of green pigments, is also of lowest Lovibond grade.

It is known that the green pigments are the most fugitive to the bleaching action of light and chemical agents. Wesson[19] has shown for two samples of cottonseed oils that the bands at 670 and 610 mμ are nearly completely removed by the treatment with Fuller's earth, and unpublished experiments of the author show the same effect after exposure to sunlight. When the brown pigments are present in considerable proportion, the removal of the green pigments does not have a large effect on the color. The absence of the green pigments would tend to confine the observed variation in chromaticity more closely to a one-dimensional range determined solely by the varying concentration of the brown pigments.

The fixed amount of yellow coloring material used in the combination of 35Y + N″R leads to the fact illustrated in Figure 8 that none of the oils included in this investigation fall exactly on the established N″ scale, hence, none of these oils are accurately matched in chromaticity by any possible combination of a fixed 35-yellow with variable red. The position of the locus of glass combinations could be brought more nearly into coincidence with the general trend of points for the vegetable oils by use of a glass of yellow numeral higher than 35. This was corroborated by some experimental work with the B group of cottonseed oils. A color comparator was used, provided with means for equalizing brightnesses, and the chromaticities of the oils and Lovibond glasses were matched as closely as possible first with 35-yellow and variable red. Then, with the red value kept constant, more yellow was added until the best chromaticity match was obtained. It was found on the average that 80-yellow was required for these oils. This shift in the locus of glass combinations would be less suitable, however, for very light cottonseed oils; for, as recorded in Table 1 and Figure 9, the oils between N″ values of 1 and 3 were graded experimentally on a low-yellow basis in the neighborhood of 20 Y.

It is evident that an improved one-dimensional Lovibond scale, which would coincide with the general trend of points for all vegetable oils would require a fixation of the yellow numeral in some functual relation to the red. For the most accurate color grading, however, a two-dimensional Lovibond scale, with independent variation of both yellow and red, is necessary to cope completely with the independent variation in pigment concentration within the group of vegetable oils.

A comparison of the luminous transmissions of the oils and Lovibond glasses in the upper part of Figure 8 shows a general agreement in lightness, but the spread of the oils in this respect is greater than can be matched by any convenient choice of the number of clear and colored glasses used in the combination while maintaining the best chromaticity match. This condition introduces serious uncertainties in the present practice of color grading, because of the residual brightness difference between the fields of the color comparator when the final chromaticity setting is made.

It is evident from the data herein presented that the accurate color grading of vegetable oils can be based only on a two-dimensional chromaticity scale, which must be embodied in a colorimeter provided also with means for the independent equalization of brightness in the sample and comparison fields. Many such two-dimensional scales could be devised and employed, provided there is no objection to the added complication in color grading. For limited ranges of color variation it is sometimes satisfactory for practical purposes to fix one of the scale variables at a constant value, or restrain its variation in some fixed relation to the other dimension, so that a one-dimensional scale is effectively established. Illustrations of these possibilities have been given for the Lovibond system of yellow and red glasses and further examples are discussed in the following section.

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[19] Cotton Oil Press 6, No. 5, September, 1922.

VI. SOME ABRIDGED COLOR-GRADING METHODS

It may be recalled that the specifications of lightness and chromaticity for the vegetable oils, as recorded in Table 1 and in Figure 8, are all referred to a standard illuminant and colorimetric method, and the properties of the observer are rigidly specified. The method is based on a knowledge of the complete spectral transmissive properties of the sample and requires extensive equipment and laborious computations to arrive at the desired results. It is essentially a method for the standardizing research laboratory and serves here as the fundamental basis for the discussion and design of abridged color-grading methods for routine application in the field. In the design of such methods, it is generally desirable to avoid the use of a large number of material color standards and to eliminate, if possible, or reduce the effect of the individual-observer variation. Whereas the illuminant and colorimetric method may be readily controlled and standardized, in general the observer must necessarily vary, and his individual color-vision characteristic may introduce serious complications in the colorimetric procedure, depending on the degree of difference existing between the spectral transmissive properties of the samples to be graded and the color standards defining the chromaticity scale. This difference may exist regardless of the degree of agreement in lightness or chromaticity obtainable between the samples and the standards of color.

It is beyond the scope of the present paper to give a detailed discussion of the application of the Lovibond method—or other abridged colorimetric methods—in the color grading of vegetable oils. The following remarks are included, however, on methods that have been investigated to some extent in connection with the present work, or that are obviously suggested by a consideration of the fundamental data herein presented. The former methods are one-dimensional by design. The latter methods are essentially two-dimensional, but may be reduced to one dimension as previously described, if the simplification is in conformity with practical requirements.

In an attempt to avoid all material color standards and effectively eliminate the properties of the observer, efforts were made during the early part of this work to discover a suitable one-number index to the chromaticity of the oils which could be expressed as a simple functional relationship between transmittances at selected wave lengths in the visible spectrum. An important condition imposed on the problem was the possibility of embodying the method in a practical oil-grading instrument measuring only transmittances at the selected wave lengths. In general, it was found that such abridged spectrophotometric methods were not wholly satisfactory, chiefly because they did not deal adequately with the independent variation of the concentrations of more than one important pigment in the oils. Unavoidable complexities in the experimental and computational aspects of the method made it doubtful if sufficient practical advantage was gained to warrant its routine application in the field.

An attempt was made by Priest[20] and the author to use a small number of selected samples of cottonseed oils as material color standards against which given cottonseed oils might be matched in chromaticity by the proper choice of their thickness alone. The thickness of the oil, or some suitable function thereof, could be used then as a one-number index to chromaticity. A color comparator was constructed in which the sample field was illuminated by a standard illuminant through a controlled variable thickness of the given sample of oil. The comparison field was illuminated by the same source through a fixed thickness of one of the oil standards. Several standards of different spectral type or thickness could be employed if desired. It was found that vacuum-sealed oils devoid of the green pigments were more stable in color than others, but none of the oils investigated proved sufficiently stable over a period of several months to serve as satisfactory color standards. The use of various yellow solutions instead of the oils, as color standards in this method, is suggested by the work of Arny, Kish, and Newmark[21], but no conclusive investigation has yet been made of the possibilities of such solutions in connection with this variation-in-thickness method.

The classification of the oils into two principal spectral types suggests a color grading method based on the use of two standard solutions of fixed concentration and of proper spectral type to represent, respectively, the brown and green groups of pigment components in the oils. Light transmitted by variable thicknesses of the solutions (in series) would be compared with light transmitted by a fixed thickness of the oil. Then, by suitable choice of a fixed thickness of one solution with a variable thickness of the other, or by varying the relative and absolute thicknesses of both, either one- or two-dimensional chromaticity scales could be established, as desired. The latter variation corresponds precisely to the concentration variation in the vegetable oils. In view of the fact that all vegetable oils may be matched in chromaticity by suitable choice of yellow and red Lovibond glasses, it is certain that the double series of glass standards could be replaced by the two solution standards, which, because of a closer relation to the oil pigments in spectral transmissive properties, would not only provide the same chromaticity matches but would also reduce the disturbing effect of the color vision characteristics of the observer. Further investigation is required to discover suitable solutions for these standards which would be satisfactory with respect to stability, reproducibility, and spectral transmittance.

An inspection of the (r, g) diagram in figure 8 shows that a convenient and reproducible one-dimensional chromaticity scale is provided by the regular sequence of spectrum colors. From the reddest vegetable oils through the range of prime cottonseed oils the spectrum colors and the oil colors are nearly equal in chromaticity. This close agreement holds also for some very light oils of the F group. The evaluation of the oil colors on this wave-length scale has been described in section IV, and the λ values recorded in column 9 of Table 1, for the standard observer on the O.S.A. colorimetric system. Unfortunately, any attempt to incorporate this simple chromaticity scale into a practical color grading method must seriously involve the color vision characteristics of each different observer assigned to the color measurements. This condition follows from the wide difference in spectral energy distribution existing between the light transmitted by the oils and that of a narrow wave-length band centered at the λ-value required to obtain the nearest chromaticity match with the oils. It is known that under such conditions normal observers would vary in their individual λ-values by amounts equiva-

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[20] Report of Proceedings of the Sixth Annual Convention of the Society of Cotton Products Analysis. Birmingham, May, 1915, p. 67. Cotton Oil Press, July, 1919;

[21] J. Ind. & Eng. Chem., 11, 950 (1919), p. 87.

lent to 2 or 3 red units on the scale of 35Y + N"R. Hence, the use of this method would require a separate calibration of each observer making the color measurements. This would call for perhaps several glass or liquor filters standardized for the purpose and having spectral transmissive properties approximating closely those of the oils. The added complication in the colorimetric procedure nullifies the apparent advantages of this simple basis for color grading.

It is also shown in figure 8 that a system of standard colors slightly less saturated than the pure spectrum colors is required to obtain exact chromaticity matches with all the oils. This condition could be realized by an extension of the method just described in which the pure spectrum colors would be diluted slightly by admixture with a variable amount of "white" light from the standard illuminant. A two-dimensional chromaticity scale is thus established by the independent variation of both wave length and purity, but the method is subject to the same practical objections as the simpler method just described.

Another extension of the simple spectrum method is possible which would largely eliminate the variation in scale settings obtained by different observers. Instead of using a narrow band of wave lengths, alone or admixed with white, the chromaticity of an oil could be accurately matched by use of a single wide band of wave lengths, covering roughly the same wave-length range as is transmitted by the oil itself.

In a colorimeter based on this principle, the comparison field would be illuminated by light from the standard illuminant after transmission through a selective light filter consisting essentially of the slit-lens-prism arrangement of an ordinary monochromator used with exceptionally wide slits. A control of the widths, position, and form of the slits would provide a wide variation in form of the curve of spectral transmission for this filter. In particular, all wave lengths in the red could be transmitted, as is done by the oils, and all wave lengths shorter than a certain value cut off completely. The cut-off could be made abrupt or gradual, as desired, to simulate most closely the spectral transmissive properties of the oils. It may be recalled that this is the condition required to reduce or eliminate from the method the variable color vision characteristics of the observer, and may be satisfied in this method perhaps even better than is done by the use of Lovibond glass combinations. The sample field of the colorimeter would be illuminated by the standard illuminant through a fixed-thickness of oil, and independent means provided for equalizing the brightnesses of the sample and comparison fields.

The chief advantage of this method lies in the avoidance of all reference to material color standards. Again, as in other color grading methods herein considered, one- or two-dimensional chromaticity scales could be established, as desired, the scale variables being related to instrumental parameters involving the position, width, or form of the slits. Considerable research and development work would be necessary to determine the best procedure in the practical application of the method.

In regard to all color-grading methods, it may be noted that scale variables in one method are always convertible into corresponding scale variables in another method. Such conversions are illustrated in the present paper by the transformation of scale values in the O.S.A. system to values on the special N" scale and the λ scale. In accordance with the single or double dimensionality of the scales, we deal respectively with nearest or exact chromaticity matches. Hense, it is always possible, upon the adoption of any improved method for the color grading of vegetable oils, to supply conversion tables along with the method, or perhaps to calibrate the scale of the colorimeter itself, so that results could be given in Lovibond terms until it is deemed desirable to use only the terms suited to the revised grading system itself.

VII. SUMMARY AND CONCLUSIONS

1. The spectral transmittance and colorimetric properties of 125 vegetable oils are presented in tabular and graphical form. The investigation includes 111 cottonseed, 3 peanut, 5 soybean, 2 sesame, 1 rape, 1 corn and 2 olive oils.

2. The oils in a 5¼ inch thickness, may be classified roughly into two general spectral types, determined, respectively, by the varying concentrations of two principal groups of pigment components. One group includes the green materials derived from chlorophyll; the other group includes perhaps several yellow or amber-colored materials of unknown identity.

3. With respect to spectral transmissive and colorimetric properties, there is no essential difference between the cottonseed and the other vegetable oils included in this investigation. Hence the problem of color grading over the range of cottonseed oils apparently encompasses that for all vegetable oils.

4. The spread in lightness over the group of vegetable oils is greater than can be conveniently matched in the present method of color grading, in which the number of clear and colored glasses used with the Lovibond tintometer is varied while maintaining the best chromaticity match in the fields of the instrument. An improved color comparator is desirable, providing a more suitable arrangement for equalizing brightnesses of the sample and comparison fields.

5. The independent variation in relative and absolute concentrations of the several pigments present in the oils makes it impossible to represent all oils accurately on any one-dimensional chromaticity scale. For accurate color grading in the Lovibond system, this situation demands the introduction into trade practice of a two-dimensional Lovibond scale established by the independent variation of both yellow and red. It is shown that the best yellow numeral varies approximately from 20 for very light cottonseed oils to 80 or above for the prime yellow oils. An improved one-dimensional Lovibond scale would be provided by the *fixation of yellow* in some definite relation to red.

6. A brief discussion is given of some color grading methods based on the following principles:

(1) The measurement of transmittances at a few selected wave lengths and the combination of these quantities in suitable relation to one another to yield a satisfactory one-number index to chromaticity.

(2) The grading in terms of a variable thickness of a sample oil required to obtain a nearest chromaticity match with a fixed thickness of a standard oil or standard solution.

(3) The grading of a fixed thickness of the sample oil in terms of the variable thicknesses of two standard solutions of fixed concentration (in series), representing, respectively, the brown and green pigment groups in the oils.

(4) The use of a variable light filter constructed on the principle of the well-known monochrometer, but provided with special control of the position, width, and form of the slits, so that the spectral transmission of this filter could be controlled and made to conform as

closely as possible to the spectral transmission of the oils to be graded.

7. Some experimental work is described on the application of methods (1) and (2) to cottonseed oils. It was found, however, that the oils themselves were not sufficiently stable in color to serve as satisfactory color standards. Other possible standards were not investigated. Both methods were deemed unsuitable for routine commercial application, however, chiefly because of complications involving the independent variation in concentration of more than one important pigment in the oils. Each of these methods was designed to establish a practical one-dimensional chromaticity scale. Methods (3) and (4) provide the possibility of either one- or two-dimensional scales for all oils, but no experimental work has been done on the methods. They are suggested by the fundamental data presented in the paper.

NOTE: CONCERNING THE EFFECT OF VARYING THE CONDITIONS OF THE AIR BLOWING ACCELERATED TEST FOR OILS AND FATS

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During our tenure of Industrial Research Fellowships at the Bureau of Chemistry and Soils of the U. S. Department of Agriculture, one of us[1] proposed a method of following the course of the oxidative deterioration of unsaturated oils and fats by means of an accelerated aging test. This method consisted of two parts: a. the accelerated "aging" process and b. the chemical determination of the extent of the oxidation. Since that time various workers have made critical studies and have proposed certain refinements in the procedure. These refinements have been mostly concerned with the first part, namely the accelerated "aging" or oxidation conditions. The most complete and detailed study of the aging conditions was made by King et al[2] in a recent paper in this Journal. These authors have carefully standardized the conditions of the accelerated aging by establishing certain very definite working limits. The most exacting of these limits was the rate of air flow used in blowing the samples. This entailed a very tedious and time-consuming calibration of several pieces of thermometer-capillary tubing, to give identical flow rates at any given pressure. Furthermore the flow rate which was used for this calibration was arbitrarily chosen as a purely empirical rate.

Shortly after the presentation[3] of the method proposed by Wheeler, it appeared more practicable to adopt a much lower air-flow rate for our subsequent work, namely, 4.8 liters per hour instead of the reported value of ten liters per hour. The subsequent appearance of the modified conditions specified by King and co-workers wherein another flow rate was used precluded the possibility of making a direct comparison of the data given in these papers. Furthermore, since King's paper contained valuable data resulting from a series of inter-laboratory compilations, it was deemed advisable to find a method whereby the various sets of data may be assembled.

A variable which has received little or no attention is the type or structure of the blowing jet used. It is obvious that the number of bubbles emitted by the same volume of air or flow-rate, would vary within wide limit depending upon the structure of the jet aperture or apertures. Wheeler (loc. cit.) specified the jet aperture empirically having no data at that time regarding the possible effect of a variance in this condition.

Experimental

I. *Effect of Rate of Air Flow During Aeration*

The apparatus used in these experiments was identical to that used by Wheeler (loc. cit.) at the Bureau of Chemistry, United States Department of Agriculture. However, a mechanical air pump was used here and the air humidified by bubbling through water. Also a bottle of acidified permanganate solution as shown by King et al, (loc. cit.) was included in the air line. The flow rate for each of the sixteen positions was measured by a calibrated flow meter, covering a range of 1-20 liters per hour at a pressure of two inches of mercury.

Reasoning from purely theoretical considerations we fully expected that the flow rate when varied over at least a two-fold range would affect the peroxide content of the oil or fat at any given point. First of all, it is generally held that the peroxide content is dependent upon at least two simultaneous actions, namely their formation and their decomposition. Taüfel and Seuss[4] indicate that oxygen itself may be split off or regenerated during the decomposition of the peroxides. This in addition to the keto-carbonyl products formed during the peroxide decompositions accounts for at least three simultaneous reactions all being presumably accelerated by the high temperature and the air blowing. Considerable evidence has accrued lately indicating that such active oxygen is regenerated as shown by the fact that the peroxide content accounts for only about half of the oxygen absorbed using a closed dynamic system.

Therefore with at least these three reactions involved it seems highly improbable that all three would be energized at exactly the same rate at widely varying air blowing rates. For example, if a

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[1] Wheeler, Oil and Soap, **9**, 89-97, (1932).

[2] King, Roschen and Irwin, Oil and Soap, **10**, 105-9, (1933).

[3] Read before A. O. A. C. meeting at Chicago, November, 1931.

[4] K. Taüfel and A. Seuss, Fettchem. Umschau 6 (2), 107-113 (1934).