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AN INVESTIGATION OF THE SUITABILITY OF SOY BEAN OIL FOR CORE OIL

BY

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AND

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AN INVESTIGATION OF THE SUITABILITY OF SOY BEAN OIL FOR CORE OIL

I. Introduction

1. *Introductory.*—Soy beans were first introduced and successfully grown in the United States in the year 1804,* although it was not until the year 1898, when the United States Department of Agriculture introduced and planted several varieties of the beans, that any serious attempt was made to grow and produce large quantities of soy beans in this country. At the present time a number of uses have been found for soy bean oil. Some of these uses were developed only after careful and diligent work on the part of the investigators.

Since some core oil manufacturers have used soy bean oil as a diluent for core oils, it has been suggested that an investigation should be undertaken in order to determine the suitability of soy bean oil either as a substitute for, or a diluent of, other oils used for the purpose of making cores. In response to these suggestions tests were conducted on various soy bean oils, each oil being designated by a letter, to serve as identification in this report.

2. *Objects of Investigation.*—This investigation was conducted (a) to determine the tensile strength of cores made with raw, semi-refined, and varnish soy bean oils under standard conditions; (b) to determine the tensile strength of cores made with various mixtures of kerosene, Japan drier, and raw soy bean oil; (c) to determine the tensile strength of cores made with various mixtures of linseed oil, soy bean oil, and kerosene.

3. *Acknowledgments.*—This investigation has been part of the work of the Engineering Experiment Station of the University of Illinois, of which Dean M. S. Ketchum is the director, and of the Department of Mechanical Engineering of which Prof. A. C. Willard is the head. Acknowledgment is made to Prof. A. P. Kratz, Research Professor of Mechanical Engineering, for valuable aid and suggestions in analyzing the results of the investigation.

Acknowledgment is also made to the Allied Mills, Peoria, Illinois; Ralston-Purina Company, St. Louis, Missouri; Funk Brothers, Bloomington, Illinois; Staley Sales Corporation, Decatur, Illinois; Standard

*Piper and Morse, "The Soybean," page 38.

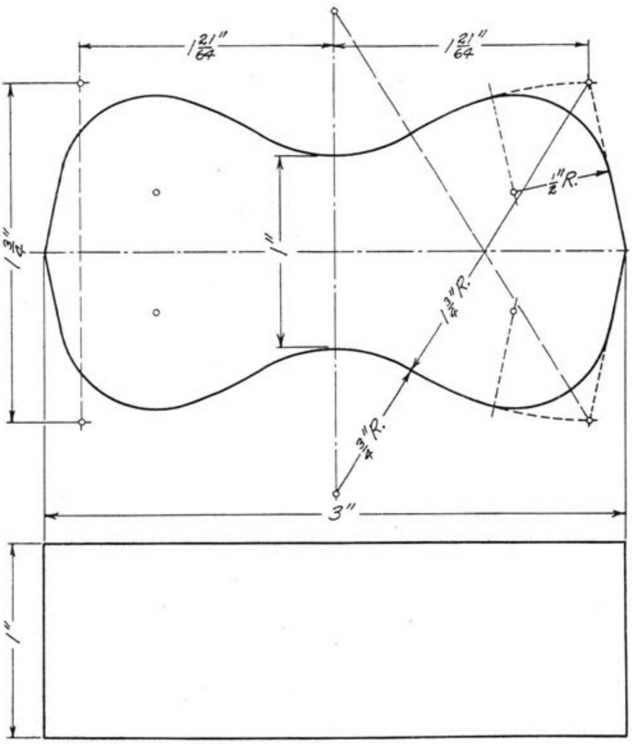

Fig. 1. Tensile Test Core

Soy Bean Mills, Centerville, Iowa; Superior Linseed Works, Cedar Rapids, Iowa; Evans Milling Co., Indianapolis, Indiana; and The Shellabarger Grain Products Company, Decatur, Illinois, for furnishing the samples of oil used in the investigation.

II. Apparatus

4. *Apparatus Used in Investigation.*—The equipment recommended by the American Foundrymen's Association was used in the preparation and testing of cores for tensile strength.* It consisted of a paddle-type sand mixer, a standard box (see Fig. 1 for dimensions of core), a standard rammer, a number of core plates, a thermostatically controlled electric oven accurate to plus or minus 5 deg. F., a balance, a set of weights, and a tensile strength testing machine.

In finding the iodine numbers of the oils a standard $\frac{N}{10}$ sodium

*Standard and Tentatively Adopted Methods of Testing and Grading Foundry Sand, A.F.A., 1928, pp. 62-66.

thiosulphate solution, a standard monochloride solution (Wij's), a standard $\frac{N}{10}$ potassium dichromate solution, a 10 per cent solution of potassium iodide, chloroform, a glass-stoppered bottle, burettes, and a watch were used.

III. Methods

5. *General Method of Procedure.*—The method of procedure adopted consisted of the preparation and baking of cores of each oil by standard methods adopted by the American Foundrymen's Association.* A number of cores from each soy bean oil were prepared and baked for different lengths of time and tested for tensile strength. The average tensile strength of the cores prepared with each soy bean oil was determined.

The average tensile strength of the cores prepared with each kind of soy bean oil was correlated with the baking time to determine the effect of the baking time on the average tensile strength of the cores.

A like number of cores were prepared with raw soy bean oil and varying proportions of Japan drier and kerosene and baked for different lengths of time. This was done to determine the effect of Japan drier and kerosene on the tensile strength of the cores and the effect of Japan drier on the speed of baking of the soy bean oil in the oven.

Similarly, a like number of cores were prepared with linseed oil and varying proportions of raw soy bean oil and kerosene and the cores baked for different lengths of time. This was done to determine the effect of the additions of raw soy bean oil and kerosene on the tensile strength of the cores.

The iodine numbers of all the soy bean oils used in the investigation were determined and the iodine numbers were also determined for a number of mixtures of raw soy bean oil and kerosene used in the investigation. The average tensile strengths of the cores prepared and baked for one hour with each mixture of soy bean oil and kerosene were correlated with the iodine numbers of the oils. The average tensile strength of the cores made and baked for one hour with the soy bean oils was also correlated with the iodine numbers of the oils. This was done in both cases to determine whether or not there was a definite relation between the average tensile strengths of the cores and the iodine numbers of the mixtures of raw soy bean oil and kerosene, and the soy bean oils.

*Standard and Tentatively Adopted Methods of Testing and Grading Foundry Sand, A.F.A., 1928, pp. 62-66.

TABLE 1
FINENESS OF WASHED SILICA SAND USED IN INVESTIGATION

U. S. Sieve No.	Percentage Remaining on Sieve	U. S. Sieve No.	Percentage Remaining on Sieve	Remarks
40	0.00	200	2.30	A. F. A. classification places this sand in Class No. 4.
70	2.25	270	0.40	
100	88.30	Pan	0.30	
140	6.30			

6. *Determination of Tensile Strength of Cores.*—Dry washed silica sand having a fineness analysis and fineness number as given in Table 1 was used to prepare all of the cores in this investigation. The chemical analysis of the sand was SiO_2 98.65 per cent, Fe_2O_3 0.10 per cent, traces of Al_2O_3, MgO, CaO and traces of the alkalies.

A ratio of seventy-five parts of sand to one part of oil, by weight, was used in preparing the core sand mixtures, and one per cent of water by weight was added to each mixture.

Eighteen cores were prepared and baked from each mixture of sand. Six of the cores were baked at a temperature of 450 deg. F. for 45 minutes, six were baked at a temperature of 450 deg. F. for one hour, and six were baked at a temperature of 450 deg. F. for one and one-fourth hours.

After being cooled to room temperature, the cores from each mixture of oil, water, and sand were tested for tensile strength and the results averaged in order to determine a characteristic value for each oil.

7. *Determination of Iodine Number.*—From 0.3 to 0.5 gram of oil was weighed and transferred to a glass-stoppered bottle. Ten cubic centimeters of chloroform was added to dissolve the oil and 40 cc. of the iodine monochloride solution (Wij's) added with a burette. The iodine solution was allowed to act on the oil for 15 minutes and then 10 cc. of a 10 per cent solution of potassium iodide was added, and about 100 cc. of distilled water was used to wash down the sides of the bottle and stopper. A freshly prepared starch solution was used as an indicator and the excess of iodine titrated with the standard $\frac{N}{10}$ sodium thiosulphate solution. At the same time a blank determination was run on the iodine solution (Wij's), chloroform, potassium iodide solution, distilled water, and starch solution. The number of cubic centimeters of sodium thiosulphate solution used, subtracted from the

amount required for the blank, represents the amount of iodine absorbed by the oil. The equivalent weight of the iodine thus found was divided by the weight of the oil taken, and the result expressed in per cent as the iodine number of the oil. To illustrate the calculations the following example is given:

The weight of oil taken was 0.4420 gram. The factor of $\frac{N}{10}$ sodium thiosulphate solution as determined against the exactly standard $\frac{N}{10}$ potassium dichromate solution was found to be 0.9523.

The 40 cc. of Wij's solution was added to the blank determination. It required 79.6 cc. of $\frac{N}{10}$ sodium thiosulphate solution to titrate this blank determination. Forty cubic centimeters of Wij's solution was also added to the 0.4420 gram of oil. It required 31.0 cc. of $\frac{N}{10}$ sodium thiosulphate solution to titrate the excess of Wij's solution.

Then 79.6 cc. minus 31.0 cc., or 48.6 cc., is equivalent to the number of cubic centimeters of sodium thiosulphate solution absorbed by the oil.

To find the equivalent amount of iodine that 48.6 cc. represents, the 48.6 cc. is multiplied by 0.12787 gram, the equivalent weight of iodine represented by one cubic centimeter of an exact tenth normal solution of sodium thiosulphate, thus

$$0.1287 \times 48.6 = 6.234 + \text{grams}$$

But the sodium thiosulphate solution was not exactly tenth normal. Therefore, the 6.234 + grams is multiplied by the factor of the sodium thiosulphate, thus

$$6.234 \times 0.9523 = 5.9366 + \text{grams}$$

This weight of iodine absorbed by the oil divided by the weight of the sample taken is expressed as the iodine value of the oil; thus

$$\frac{5.9366}{0.4420} = 134.3, \text{ iodine value of the oil.}$$

IV. Results of Tensile Strength Tests

8. *Tensile Strength Tests on Cores Made with Soy Bean Oils.*—Table 2 gives the average tensile strength of the cores made with the soy bean oils when baked for different lengths of time. Figure 2

TABLE 2
TESTS OF CORES MADE WITH SOY BEAN OILS

Baking Time		45 min.	1 hr.	1¼ hr.	15 min.
Oil	Classification	Average Tensile Strength lb. per sq. in.	Average Tensile Strength lb. per sq. in.	Average Tensile Strength lb. per sq. in.	Iodine Number (Wij's)
A	Raw	75	137	125	135
B	Raw	69	131	122	128
C	Raw	67	127	120	127
D	Raw	68	128	121	128
E	Raw	63	125	119	123
F	Raw	72	135	125	129
G	Raw	80	140	129	133
H	Raw	85	148	136	141
I	Semi-Refined	70	129	122	127
J	Semi-Refined	69	131	122	127
K	Semi-Refined	71	130	120	130
L	Refined Varnish Oil	68	128	119	129

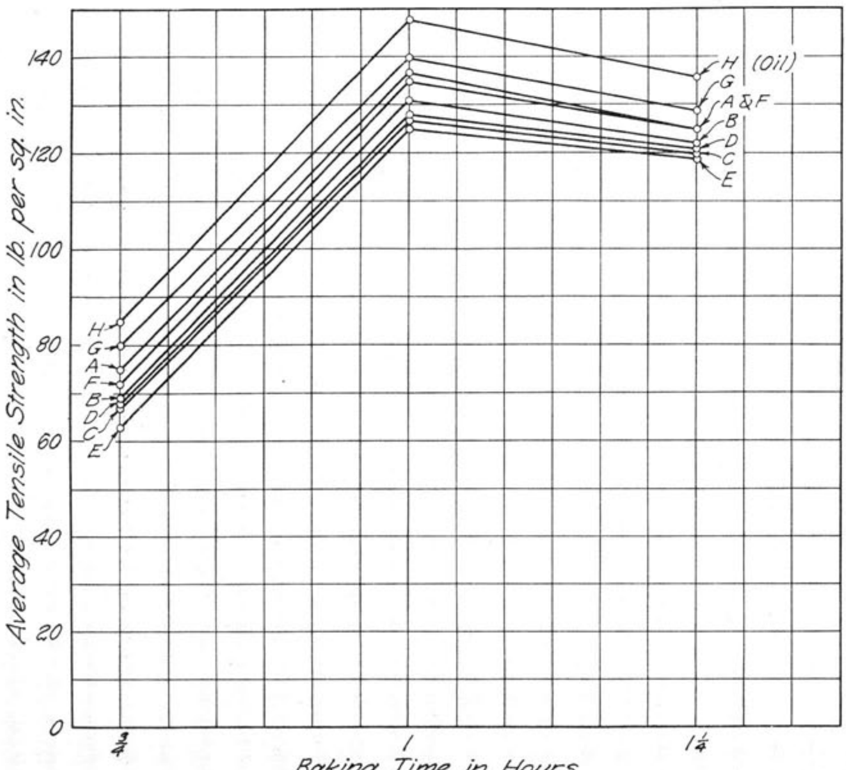

FIG. 2. RELATION OF AVERAGE TENSILE STRENGTH OF CORES MADE FROM RAW SOY BEAN OILS TO BAKING TIME

TABLE 3
TESTS OF CORES MADE WITH RAW SOY BEAN OIL, KEROSENE AND JAPAN DRIER

Baking Time			45 min.	1 hr.	1¼ hr.	15 min.
Raw Soy Bean Oil per cent by weight	Kerosene per cent by weight	Japan Drier per cent by weight	Tensile Strength lb. per sq. in.	Tensile Strength lb. per sq. in.	Tensile Strength lb. per sq. in.	Iodine Number (Wij's)
100	None	None	80	140	129	131
90	10	None	95	119	118	121
85	15	None	85	112	110	114
75	25	None	80	98	94	101
70	30	None	75	92	85	94
50	50	None	55	65	55	66
40	60	None	45	52	48	53
30	70	None	33	40	30	39
20	80	None	22	28	20	27
10	90	None	11	15	8	14
95	None	5	90	122	119	..
90	None	10	95	129	125	..
85	None	15	100	134	128	..
85	10	5	80	113	110	..
80	10	10	85	115	110	..
75	10	15	85	117	112	..
70	20	10	70	103	101	..
65	20	15	68	99	97	..
60	30	10	70	100	95	..
55	30	15	65	90	83	..

is a graphical representation of the results, and shows that the average tensile strength of the cores made with the raw soy bean oils that were baked 45 minutes varied from 63 to 85 lb. per sq. in.; the average tensile strength of the cores that were baked one hour varied from 125 to 148 lb. per sq. in.; and, the average tensile strength of the cores that were baked 1¼ hours varied from 119 to 136 lb. per sq. in. It is noted that the average strength of the cores made from oil E was lowest for the three baking periods and that of the cores from oil H was highest.

Figure 2 also shows that all the cores made from the oils reached their maximum tensile strengths when baked one hour. All cores baked for 45 minutes were light brown in color, while all cores baked for one hour were brown. Cores baked for 1¼ hours were a shade darker than those baked for one hour. The color of cores is an indication of the completeness of oxidation. A light brown color indicates that oxidation is not complete and is an indication of deficiency in strength, while a dark brown color indicates over-oxidation, and is also an indication of weakness.

9. *Tensile Strength Tests on Cores Made with Raw Soy Bean Oil and Kerosene.*—Table 3 gives the average tensile strength of the cores made with raw soy bean oil and kerosene when baked for different

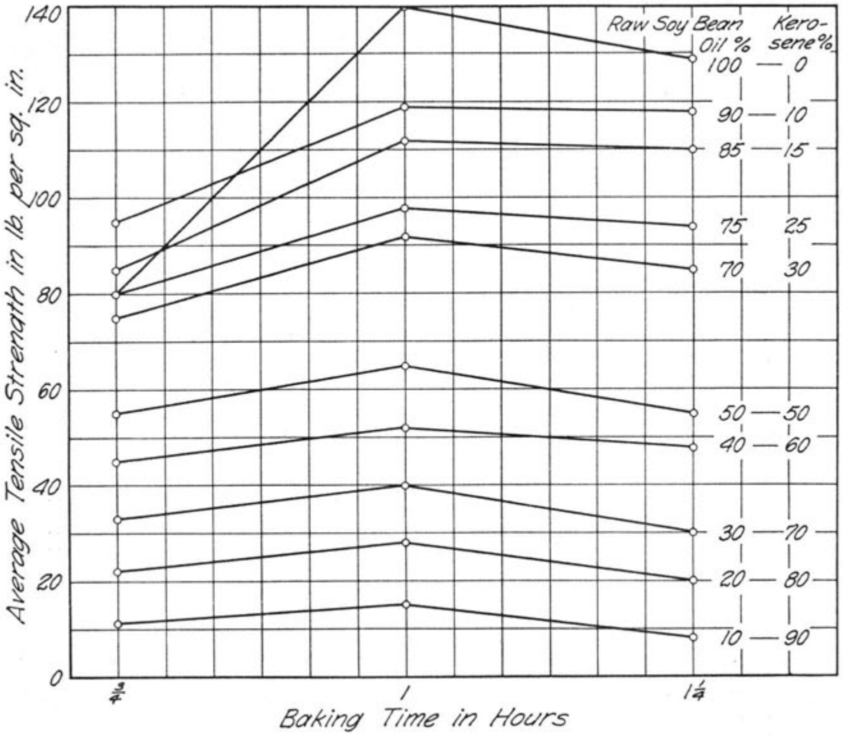

FIG. 3. RELATION OF AVERAGE TENSILE STRENGTH OF CORES MADE FROM MIXTURES OF SOY BEAN OIL AND KEROSENE TO BAKING TIME.

lengths of time. All mixtures of kerosene and raw soy bean oil were made by weight. Figure 3 is a graphical representation of these results and shows that cores made with pure raw soy bean oil had an average tensile strength of 80 lb. per sq. in. when baked for 45 minutes, 140 lb. per sq. in. when baked one hour, and 129 lb. per sq. in. when baked 1¼ hours.

It can be seen from Fig. 3 that as the percentage of soy bean oil is decreased and the percentage of kerosene is increased the tensile strength of the cores from each mixture is decreased. It also shows that the maximum tensile strength of the cores made with the various mixtures of raw soy bean oil and kerosene was reached when the cores were baked one hour.

10. *Tensile Strength Tests of Cores Made with Raw Soy Bean Oil, Kerosene, and Japan Drier.*—Table 3 gives the average tensile

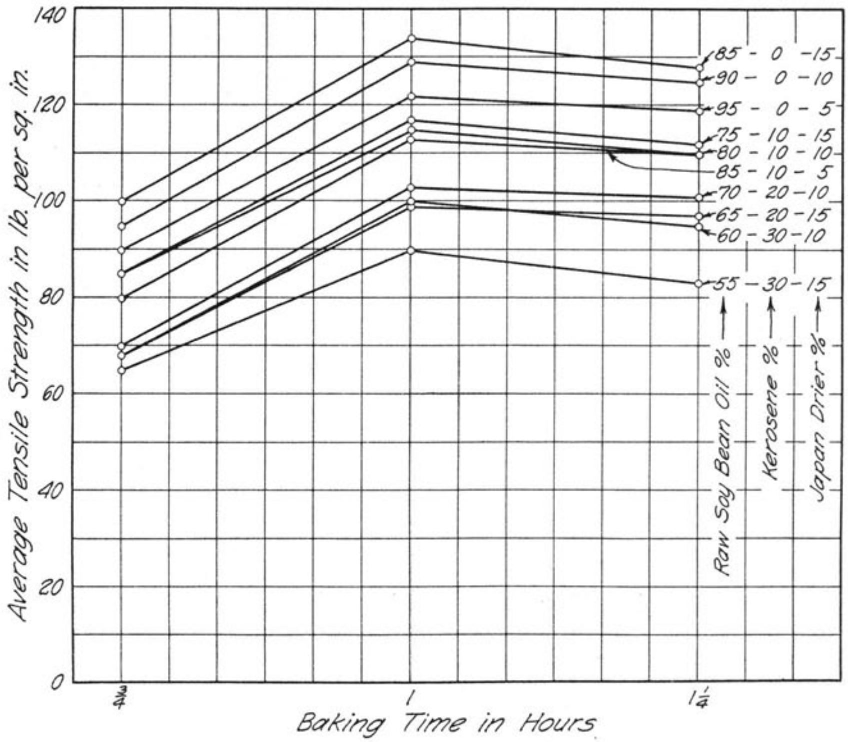

FIG. 4. RELATION OF TENSILE STRENGTH OF CORES TO BAKING TIME

strength of the cores made with raw soy bean oil, kerosene, and Japan drier when baked for different lengths of time. Figure 4 shows graphically the effect of additions of Japan drier to raw soy bean oil on the tensile strength of the cores made from the mixtures. It also shows the effect of additions of both kerosene and Japan drier to raw soy bean oil on the tensile strength of the cores made from the mixture.

Figure 4 shows that cores made from a mixture of 85 per cent raw soy bean oil and 15 per cent Japan drier had greater strength for all three baking periods than those made with 90 per cent raw soy bean oil and 10 per cent Japan drier, or those made with 95 per cent raw soy bean oil and 5 per cent Japan drier. Other mixtures with increased percentages of Japan drier were not tested because it was thought that a core oil with larger percentages of Japan drier would be too expensive for practical use.

TABLE 4
TESTS OF CORES MADE WITH LINSEED OIL, KEROSENE, AND RAW SOY BEAN OIL

Baking Time			45 min.	1 hr.	1¼ hr.
Linseed Oil per cent by weight	Soy Bean Oil per cent by weight	Kerosene per cent by weight	Tensile Strength lb. per sq. in.	Tensile Strength lb. per sq. in.	Tensile Strength lb. per sq. in.
100	None	None	144	140	98
95	5	None	125	152	132
90	10	None	124	149	142
85	15	None	130	146	140
80	20	None	126	143	140
70	30	None	130	140	135
60	40	None	135	138	132
50	50	None	136	140	130
85	5	10	119	125	104
80	10	10	118	120	110
75	15	10	110	115	105
75	5	20	95	110	100
70	10	20	87	101	98
65	15	20	90	91	85
65	5	30	83	87	84
60	10	30	76	82	80
55	15	30	69	74	68

Curves for the other mixtures show that there was no gain in tensile strength from further dilution of the raw soy bean oil.

11. *Tensile Strength Tests on Cores Made with Linseed Oil and Raw Soy Bean Oil.*—Table 4 gives the average tensile strength of the cores made with various mixtures of linseed oil and raw soy bean oil when baked for different lengths of time. In Fig. 5 these results are shown graphically. When pure linseed oil was used the cores gave an average tensile strength of 144 lb. per sq. in. when baked 45 minutes, 140 lb. per sq. in. when baked one hour, and 98 lb. per sq. in. when baked 1¼ hours; while a mixture of 95 parts of linseed oil and 5 parts of raw soy bean oil produced cores with an average tensile strength of 125 lb. per sq. in. when baked 45 minutes, 152 lb. per sq. in. when baked one hour, and 132 lb. per sq. in. when baked 1¼ hours. It should be noted that cores made from 100 parts of linseed oil reached their maximum tensile strength in 45 minutes while cores made with 95 parts of linseed oil and 5 parts of raw soy bean oil reached maximum tensile strength in one hour. However, the cores made from the latter mixtures gave higher tensile strengths when baked for one hour than those made with pure linseed oil. Figure 5 shows that when more than 5 per cent of soy bean oil is added to linseed oil the cores made with the mixtures show a gradual drop in tensile strength when baked one hour. It also shows that a baking time of one hour is necessary to produce maximum tensile strength of cores made with

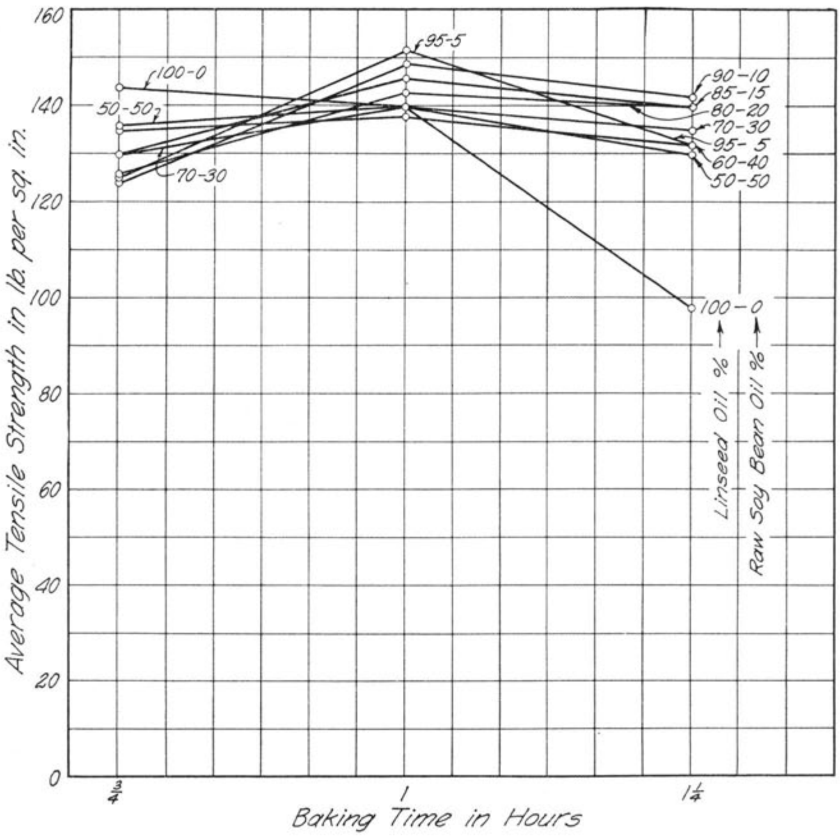

Fig. 5. Relation of Average Tensile Strength of Cores Made from Mixture of Linseed and Soy Bean Oils to Baking Time

a mixture of raw soy bean and linseed oils. However, the cores made from mixtures of 60 parts linseed and 40 parts soy bean oils and 50 parts linseed and 50 parts soy bean oils show relatively high tensile strengths for all three baking periods. This property of a core oil is of importance for the reason that cores are often allowed to remain in core ovens for indefinite lengths of time; therefore a core oil that produces cores of approximately equal tensile strength over a reasonable range of baking time has an advantage over ones that do not.

12. *Tensile Strength Tests on Cores Made with Linseed Oil, Raw Soy Bean Oil, and Kerosene.*—Table 4 gives the average tensile strength of cores made with various mixtures of linseed oil, raw soy bean oil, and kerosene when baked for different lengths of time. Figure 6

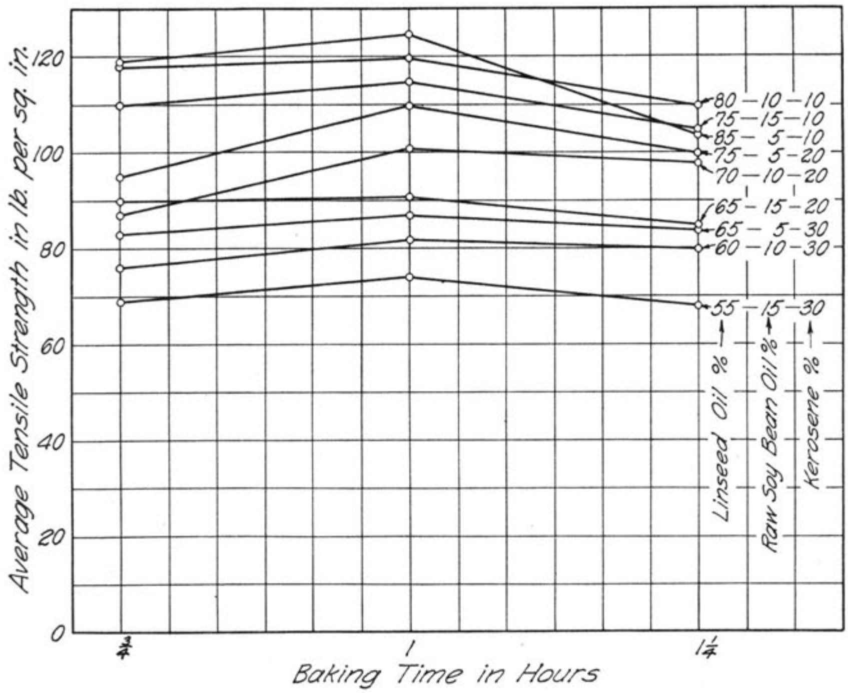

FIG. 6. RELATION OF AVERAGE TENSILE STRENGTH OF CORES MADE FROM LINSEED OIL, SOY BEAN OIL, AND KEROSENE TO BAKING TIME

shows these results graphically. A gradual reduction in the tensile strength of the cores occurs as a greater percentage of kerosene is added to the linseed and soy bean oils. However, a mixture of 65 parts of linseed oil, 15 parts of raw soy bean oil, and 20 parts of kerosene produced cores with an average tensile strength of 90 lb. per sq. in., when baked 45 minutes, 91 lb. per sq. in. when baked one hour and 85 lb. per sq. in. when baked 1¼ hours. Although this is a great reduction in tensile strength as compared with cores made from mixtures containing smaller amounts of kerosene there is the advantage of using an oil that produces cores of approximately equal tensile strengths over the whole range of baking time.

V. SIGNIFICANCE OF IODINE NUMBERS OF THE OILS

13. *Maximum Tensile Strength of Cores Compared with Their Iodine Numbers.*—Table 2 gives the iodine numbers of all the soy bean oils as submitted for investigation. Table 3 gives the iodine numbers

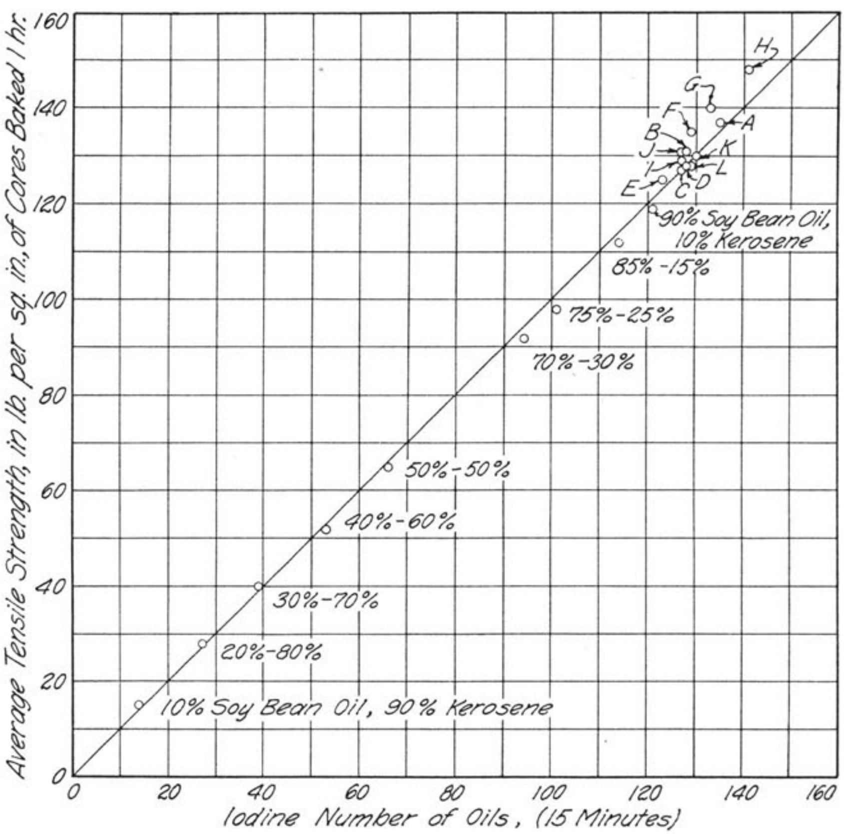

FIG. 7. RELATION OF TENSILE STRENGTH OF CORES TO IODINE NUMBER OF CORE OILS

of a number of mixtures of a raw soy bean oil and kerosene. Figure 7 is a graphical correlation of the average tensile strength of the cores made with each soy bean oil and mixture of raw soy bean oil and kerosene when baked one hour, with the respective iodine numbers of the oils and mixtures of raw soy bean oil and kerosene. The iodine numbers of the soy bean oils corresponding to the upper portions of the graph did not produce enough data to show the exact direction of the curve. Cores made with mixtures of a raw soy bean oil and kerosene were tested for additional data, and the results show that when these additional data are correlated with the results of Table 2, the average tensile strength of the cores made with each oil tested was directly proportional to the iodine number of the oil. The kerosene used was of zero iodine number and was employed both as

TABLE 5
RATIO OF TENSILE STRENGTH OF CORES TO IODINE NUMBERS OF OILS

Oil	Value of Ratio	Oil		Value of Ratio
		Soy Bean per cent by weight	Kerosene per cent by weight	
A	1.014			
B	1.023			
C	1.000	90	10	0.984
D	1.000	85	15	0.982
E	1.016	75	25	0.970
F	1.046	70	30	0.965
G	1.127	50	50	0.985
H	1.049	40	60	0.981
I	1.015	30	70	1.026
J	1.031	20	80	1.037
K	1.000	10	90	1.071
L	0.992			
Average Value of Ratio = 1.0161				

a diluent and to lower the iodine number. It is evident that a linear equation may be used to calculate the approximate tensile strength of cores made with any soy bean oil used in this investigation if the iodine number of the oil is known.

Let the iodine number of the oil be represented by x and the average tensile strength of the core by y.

Then the straight line in Fig. 7 may be expressed by the equation

$$y = cx$$

$$\text{and } c = \frac{y}{x}$$

$$\text{Hence, } \frac{\text{Tensile Strength}}{\text{Iodine Number}} = \text{a constant}$$

Table 5 gives the values of this ratio $\frac{y}{x}$ for the iodine numbers of the oils tested. It will be noted that the average value of the ratio for these oils and mixtures of oils and kerosene is 1.0161.

Substituting the value of the average constant in the equation, and assuming an iodine number of say, 130, the equation is

$$y = 130 \times 1.0161$$

Solving for y, the tensile strength of the baked cores is found to be 132.09 lb. per sq. in.; this value compares favorably with the results obtained with oil K. The actual average tensile strength was found to be 130 lb. per sq. in. The other soy bean oils and mixtures of soy bean oil and kerosene gave similar results.

The curve of Fig. 7 is a close approximation to a straight line, and the fact that the line does not pass through all the points indicates that certain discrepancies arose because it was impossible to control such variables as mixing, ramming, and baking temperature more closely.

VI. Conclusions

14. *Conclusions.*—The investigation included a variety of soy bean oils and the results should be applicable to the soy bean oils on the market at the present time. The following are the principal conclusions:

(1) Raw soy bean oil produced cores with an average tensile strength slightly higher than the average tensile strength of cores made from semi-refined or varnish soy bean oil and compares favorably with the core oils now on the market.*

(2) Cores baked for approximately one hour were of greater strength than those baked for 45 minutes and 1 hour and 15 minutes, respectively.

(3) The addition of kerosene to raw soy bean oil caused a gradual reduction in the average tensile strength of the cores as the percentage of kerosene in the mixtures was increased.

(4) The addition of Japan drier to raw soy bean oil slightly increased the tensile strength of the cores. No reduction in the length of baking time required for the cores to reach maximum tensile strength was noted.

(5) Various additions of both Japan drier and kerosene to raw soy bean oil produced cores with varying tensile strengths which followed no definite rules over the range of the data collected. No reduction in the length of the time required for the cores to reach maximum tensile strength was noted.

(6) Cores made with various proportions of linseed oil and soy bean oil were as strong as those made with linseed oil. A longer baking time was required for cores made with mixtures of soy bean oil and kerosene to reach maximum tensile strength than for cores made with linseed oil.

(7) The cores made with mixtures of linseed oil, kerosene, and soy bean oils decreased in strength as the percentages of kerosene and soy bean oil were increased.

(8) The tensile strength of the cores made with the soy bean oils,

*"An Investigation of Core Oils," Univ. of Ill. Eng. Exp. Sta. Bul. 221, 1930.

and mixtures of soy bean oil and kerosene, was found to be proportional to the iodine numbers of the soy bean oils and mixtures of soy bean oil and kerosene. The average tensile strength may be calculated from the following equation:

$$\frac{\text{Tensile Strength}}{\text{Iodine Number}} = 1.0161$$

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