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MEASUREMENT OF ELECTRICAL RESISTANCE AND MECHANICAL STRENGTH OF STORAGE-BATTERY SEPARATORS

BY

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MEASUREMENT OF ELECTRICAL RESISTANCE AND MECHANICAL STRENGTH OF STORAGE-BATTERY SEPARATORS

By C. L. Snyder

ABSTRACT

This paper outlines a method for measuring the resistance of storage-battery separators and gives the results of measurements on separators of several kinds of wood. The effect of thickness of the separators, the method of treating them, and the effect of concentration and temperature of sulphuric-acid solutions on resistance and mechanical strength of the wood are described.

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I. INTRODUCTION

The life and internal resistance of a storage battery depend largely upon certain properties of the separators, the most important of which are mechanical strength and electrical resistance. The purpose of this work was to establish, if possible, a reliable method of measuring separator resistance and to compare the properties of several kinds of wood. Separators cut and treated in various ways were tested under conditions approximating those in storage batteries.

The samples investigated were obtained from several sources. Some of them had been treated before they were received, the

others were treated in the laboratory. A method of measuring the electrical resistance is described and shown to give consistent results. Tensile-strength measurements were made on strips cut from the separators and serve to indicate the effects of the concentration and the temperature of the electrolyte on the wood fiber.

Additional experiments are desirable, but it has not been possible to extend the measurements because of the pressure of other work. The bureau has received many requests for information on this subject, and it is therefore deemed advisable to publish the results so far obtained. It is obvious that the variations between samples are considerable, but the results presented here are significant, at least qualitatively, and it is hoped to corroborate them by further experiments when the opportunity for an extension of this work is afforded.

II. DESCRIPTION OF SAMPLES AND METHOD OF TREATMENT

The separators studied were supplied by three different manufacturers designated as A, B, and C. A description of the samples is given in Tables 1, 2, and 3, respectively. The last column in these tables gives the electrical resistance in ohms for 1 square inch of separator surface. The resistance was measured by the method to be described below. The other headings in the tables are defined in the paragraphs which follow.

1. TREATMENT

The samples from manufacturer A were in three groups which had been treated by methods unknown to the bureau but designated as Nos. 1, 2, and 3. The particular methods are of no significance, except as serving to explain differences in results obtained from samples alike in other respects and as indicating variations to be expected in a commercial product.

The separators from manufacturers B and C had not been treated, and so it was necessary to treat them in the laboratory. Of the commercial methods of treatment, perhaps the most common are (1) by live steam and (2) by a solution of caustic soda. Separators were treated by each of these methods, as follows:

Method 1 consisted in subjecting the samples to live steam at approximately atmospheric pressure in a specially constructed chamber for a period of about 24 hours. The steam was reheated, as shown in Figure 1. Method 2 consisted of treating the samples

in a one-half per cent solution of caustic soda maintained near the boiling point for a period of about 16 hours, after which they were washed with distilled water until the wash water showed no alkaline reaction with litmus. The samples were then kept in acidulated water until ready for the tests. The comparison between these two methods of treatment which is to follow is not intended to show superiority of either method but, rather, the difference in their effect on the different samples.

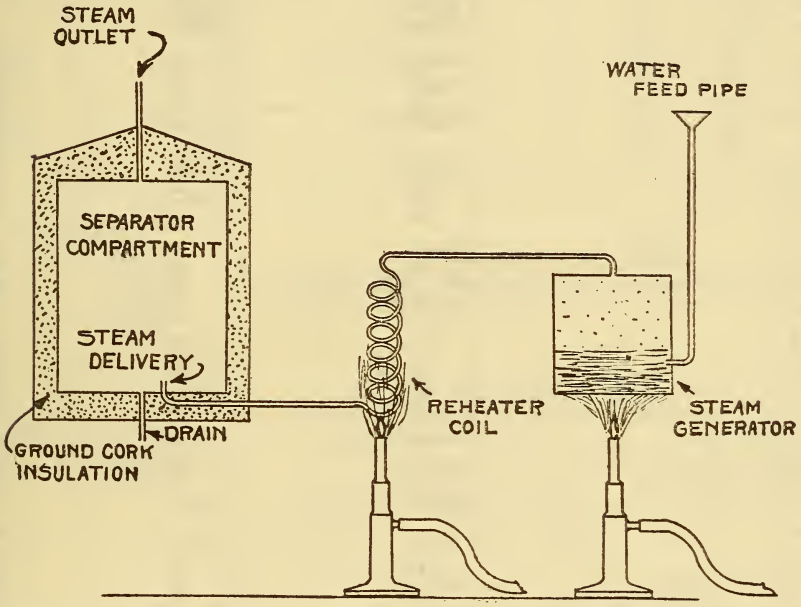

FIG. 1.—*Diagram of equipment used in the steam treatment*

2. PATTERN

The pattern of the separator refers to the shape of its cross section taken perpendicularly to the "ribs." The patterns of the different separators which were tested are shown in Figure 2 with their dimensions and designation numbers. The thickness of a separator may be measured either over the ribs or in the space between the ribs called the back web. The mean thickness was computed by dividing the total cross-sectional area by its length. Both the back-web thickness and the mean thickness are given in Tables 1, 2, and 3.

TABLE 1.—Description of Samples from Manufacturer A

[These samples were all of the same pattern and thickness, but varied in the kind of wood, method of treatment, and method of cutting. The resistance was measured in acid at 20° C. and specific gravity 1.280. Pattern No. 1; thickness of back web, 0.052 inch; mean thickness, 0.063 inch]

Sample number	Kind of wood	Treatment number	Cut	Ohms resistance, 1 square inch of surface
A-1	Cedar	1	Rotary	(1)
A-2	Fir	1	do	
A-3	Cypress	1	do	
A-4	Redwood	1	Sawn	
A-5	Cherry	1	Rotary	
A-6	Poplar	1	do	0.041
A-7	do	2	do	.034
A-8	Cherry	1	do	.047
A-9	do	2	do	.037
A-10	Basswood	1	do	.054
A-11	do	2	do	.040
A-12	Redwood	1	Sawn	.075
A-13	do	2	do	.055
A-14	do	1	Rotary	.090
A-15	do	2	do	.078
A-16	Cedar	1	do	.115
A-17	do	2	do	.079
A-18	Fir	1	do	.090
A-19	do	2	do	.084
A-20	Cypress	1	do	.137
A-21	do	2	do	.103
A-22	do	1	Sawn	.162
A-23	do	3	do	.089
A-24	do	1	Rotary	.124
A-25	do	2	do	.126
A-26	Cherry	1	do	.042
A-27	do	2	do	.034
A-28	Basswood	1	do	.054
A-29	do	2	do	.039
A-30	Cedar	3	Sawn	.057
A-31	do	1	Rotary	.085
A-32	do	2	do	.063
A-33	do	3	do	.072
A-34	Redwood	1	do	.084
A-35	do	2	do	.071
A-36	do	1	Sawn	.063
A-37	do	2	do	.045
A-38	do	3	do	.036
A-39	Poplar	1	Rotary	.040
A-40	Fir	1	do	.116
A-41	do	2	do	.074

[1] Used for breaking tests.

NOTE.—It may be noted that results for certain samples apparently alike in every respect do not check; for example, the cedar samples A-16 and A-31, A-17 and A-32, and the redwood samples A-12 and A-36, A-13 and A-37. It should be explained in that connection that the samples from manufacturer A arrived in three different shipments—A-1 to A-6, A-7 to A-21, and A-22 to A-41. The discrepancies between the samples noted are probably due to nonuniformity in method of treatment about which no data are available.

TABLE 2.—Description of Samples from Manufacturer B

[All separators sawn. Resistance was measured in acid at 20° C. and specific gravity 1.280]

Sample number	Kind of wood	Treatment	Pattern number	Back-web thickness	Mean thickness	Ohms resistance, 1 square inch of surface
				Inch	Inch	
B-1	Cedar	Steam	2	0.040	0.055	0.195
B-2	do	do	3	.036	.052	.232
B-3	Alaska cypress	do	3	.036	.052	.162
B-4	Cedar	do	2	.036	.052	.125
B-5	Redwood	do	3	.036	.052	.217
B-6	do	do	2	.040	.055	.217
BB-1	Cedar	Caustic	2	.040	.055	.117
BB-2	do	do	3	.036	.052	.120
BB-3	Alaska cypress	do	3	.036	.052	.093
BB-4	Cedar	do	2	.036	.052	.085
BB-5	Redwood	do	3	.036	.052	.065
BB-6	do	do	2	.040	.055	.085

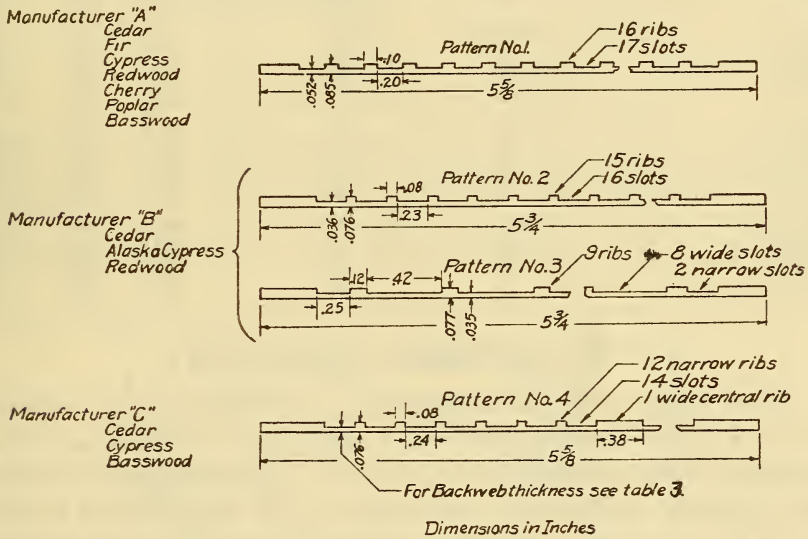

FIG. 2.—*Diagrams of the patterns of the separators*

3. CUT

There are two general methods of cutting the separators from the log. The method designated as "rotary" refers to cutting around the log tangentially, while "sawn" refers to cutting across the rings. In rotary-cut separators the rings are approximately parallel to the surface of the separator, while in "sawn" separators the rings usually appear as lines parallel to the ribs of the separator.

TABLE 3.—Description of Samples from Manufacturer C

[These samples were all of pattern No. 4, but varied in thickness for each kind of wood. The resistance was measured in acid at 20° C. and specific gravity 1.225]

Sample number	Kind of wood	Treatment	Back-web thickness	Mean thickness	Ohms resistance, 1 square inch of surface
			Inch	Inch	
C-1	Basswood	Steam	0.025	0.044	0.071
C-2	do	do	.030	.047	.088
C-3	do	do	.035	.050	.088
C-4	do	do	.040	.053	.122
C-5	do	do	.045	.056	.131
C-6	Cedar	do	.025	.044	.111
C-7	do	do	.030	.047	.175
C-8	do	do	.035	.050	.195
C-9	do	do	.040	.053	.215
C-10	do	do	.045	.056	.316
C-11	Cypress	do	.025	.044	.234
C-12	do	do	.030	.047	.273
C-13	do	do	.035	.050	.253
C-14	do	do	.040	.053	.328
C-15	do	do	.045	.056	.434
CC-1	Basswood	Caustic	.025	.044	.031
CC-2	do	do	.030	.047	.033
CC-3	do	do	.035	.050	.036
CC-4	do	do	.040	.053	.036
CC-5	do	do	.045	.056	.042
CC-6	Cedar	do	.025	.044	.075
CC-7	do	do	.030	.047	.075
CC-8	do	do	.035	.050	.092
CC-9	do	do	.040	.053	.097
CC-10	do	do	.045	.056	.120
CC-11	Cypress	do	.025	.044	.099
CC-12	do	do	.030	.047	.100
CC-13	do	do	.035	.050	.122
CC-14	do	do	.040	.053	.142
CC-15	do	do	.045	.056	.146

III. ELECTRICAL RESISTANCE

Wood when dry is a nonconductor of electricity, but the separator in a storage battery becomes a good conductor because of the sulphuric acid contained within its pores. The conduction through the separator is therefore electrolytic. The method used in this work for measuring separator resistance consisted in determining the electrolytic resistance of a specially constructed cell with and without the separator interposed across the path of the current under otherwise identical conditions. The difference between the two measurements gives the effective resistance of the separator.

The cell in which the resistance measurements were made (fig. 3) was so designed that a known area of the separator under test was interposed across the path of the current flowing between the electrodes *A A*. The effective resistance as observed when multiplied by this area gives the resistance of 1 square inch of separator surface. The space *M* between the glass plates *C C* was sufficient for two separators for which the combined resistance

could be determined. Since the combined resistance of two separators checked with the sum of their individual values, the error due to leakage around the edges of the separator was negligible.

The resistance was determined by a potential difference method with the use of a 60-cycle alternating current to avoid polarization

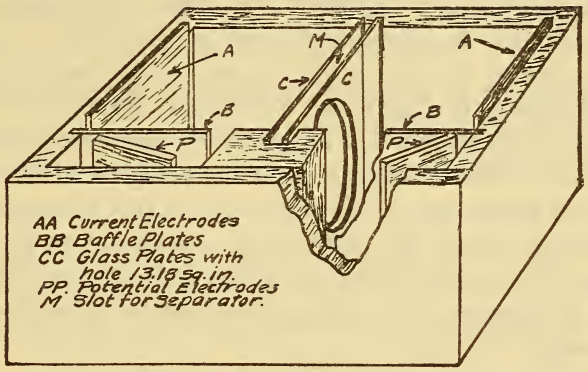

FIG. 3.—*Sketch of cell used in the resistance measurements*

effects. In the resistance cell already described the potential difference between the auxiliary electrodes *P P* was observed for a given current flowing between the electrodes *A A* and the resistance computed from Ohm's law as explained below.

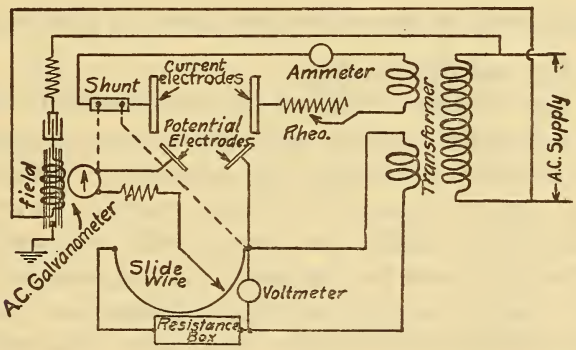

FIG. 4.—*Wiring diagram of the electrical circuits used in the resistance measurements*

The electrical circuit used for these measurements, as shown in Figure 4, was suggested by Dr. F. Wenner of this bureau. A transformer with two secondary windings each capable of carrying 5 amperes was used to transform the circuit voltage from 110 to about 10 volts in each winding. The current from one secondary was passed through the cell and was maintained at 5 amperes,

while the current from the other was passed through a known resistance, consisting of a slide-wire and a noninductive resistance (resistance box) of known value. This circuit served as a potentiometer in phase with the current through the cell. In order to balance the potential difference of a measurable length of slide-wire against the unknown drop in potential across the cell, an alternating current galvanometer was used. To keep the field of the galvanometer in phase with the potentiometer circuit, the proper amount of resistance and capacity was computed for the known inductance of the field. These were found to be approximately 400 ohms and 8 μf, respectively, for a frequency of 60 cycles. A 0.01 ohm resistance standard was placed in series with the cell, and when the measured value of this standard checked with its known value the bridge was considered to be in proper adjustment. For zero deflection of the galvanometer the drop in potential E between the potential electrodes is represented by the expression

$$E = i\,r\,n$$

where i = current through slide-wire
r = ohms per division of slide-wire
n = number of divisions.

The current i can be computed from the voltmeter reading across the resistance box and slide-wire.

The resistance R of the cell is then given by Ohm's law, $R = \frac{E}{I}$ where I is the ammeter reading.

For an approximate check of the measurements alternating current was replaced by direct current from two separate sources, using an ordinary D'Arsonval galvanometer. When frequent reversals of current between the current electrodes were made to reduce polarization effects, the results with alternating current and direct current were in sufficiently good agreement.

Without special precautions, the precision of the method described is probably well within 1 per cent. Inasmuch as the resistance of individual separators from the same lot all similarly treated varied from 5 to 15 per cent, the method is sufficiently accurate for the purpose.

1. TIME OF IMMERSION

It was found by preliminary tests that a period of two or three weeks was required for the resistance of a separator immersed in acid to reach a constant value. The results given in the tables

were obtained from separators which had been soaked for a period of three weeks in acid having an initial specific gravity of 1.280. During the period of immersion the acid had become slightly diluted and somewhat discolored. Prior to making the resistance measurements the separators were rinsed in distilled water and replaced in fresh acid. The specific gravities were then adjusted to the values as indicated in the tables.

2. ACID CONCENTRATION

Since the separator is conductive because of the acid absorbed within its pores, it was to be expected that the resistance of the separator would be proportional to the resistivity of the acid.

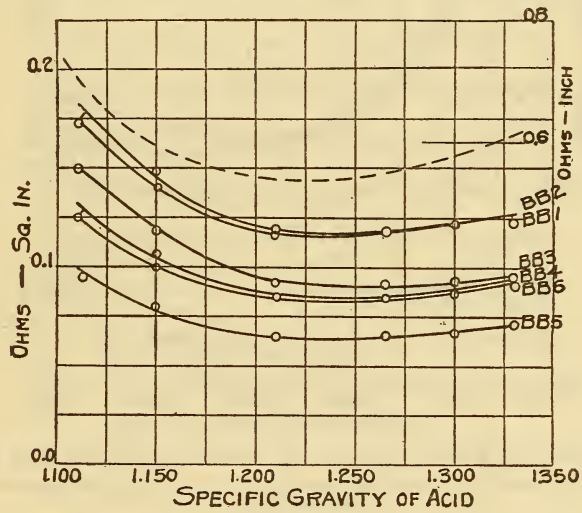

FIG. 5.—*The effect of acid concentration on the resistance of different kinds of separators*
Samples treated with caustic soda and resistance measured at 20° C. Dotted line shows the resistivity of sulphuric acid

This was found to be the case, as is shown in Figures 5 and 6, where the dotted curves represent the resistivity of sulphuric acid for the same range in concentrations as used in the experiments. The shape of the curves for separator resistance is about the same as that for sulphuric acid.

3. METHOD OF TREATMENT

The samples treated by the caustic-soda method were found to have somewhat less than one-half the resistance of those treated by the steam method. This is shown by the ratios (Table 4) between like separators treated by the different methods. The values in Table 4 were taken from the curves of Figure 8. The

effect of the caustic-soda method in lowering the resistance was previously observed in the samples represented in Figures 5 and 6, where the mean value for those treated by the caustic-soda method was approximately one-half of that for the steam-treated samples.

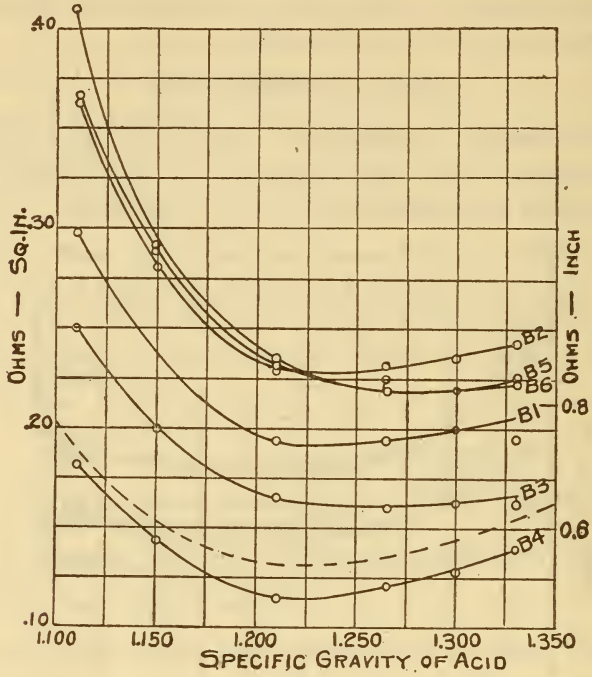

FIG. 6.—*The effect of acid concentration on the resistance of different kinds of separators*

Samples treated with steam and the resistance measured at 20° C. Dotted line shows the resistivity of sulphuric acid

4. TEMPERATURE

The effect of temperature on resistance was determined by measurements at temperatures from 10 to 30° C., and the results are given in Figure 7 for two typical cases. The temperature coefficient of resistance in the neighborhood of 20° C. is about −2 per cent, or approximately that of sulphuric acid. The resistances given in Tables 1, 2, and 3 were measured at approximately 20° C., and because the fluctuations in temperature for 1 or 2°, as compared with the variations in resistance of duplicate samples were small no corrections were made for temperature.

TABLE 4.—Comparison of Resistance Values of Samples Treated by Different Methods—No. 1, Steam Treatment; No. 2, Caustic Treatment

[Samples supplied by manufacturer C]

Kind of wood	Thickness of back web (inch)								
	0.025			0.035			0.045		
	Ohms for 1 square inch		Ratio	Ohms for 1 square inch		Ratio	Ohms for 1 square inch		Ratio
	No. 1	No. 2	No. 2/No. 1	No. 1	No. 2	No. 2/No. 1	No. 1	No. 2	No. 2/No. 1
Basswood	0.07	0.026	0.37	0.10	0.035	0.35	0.136	0.044	0.31
Cedar	.13	.062	.48	.195	.090	.46	.280	.118	.42
Cypress	.208	.085	.41	.30	.122	.41	.415	.164	.40

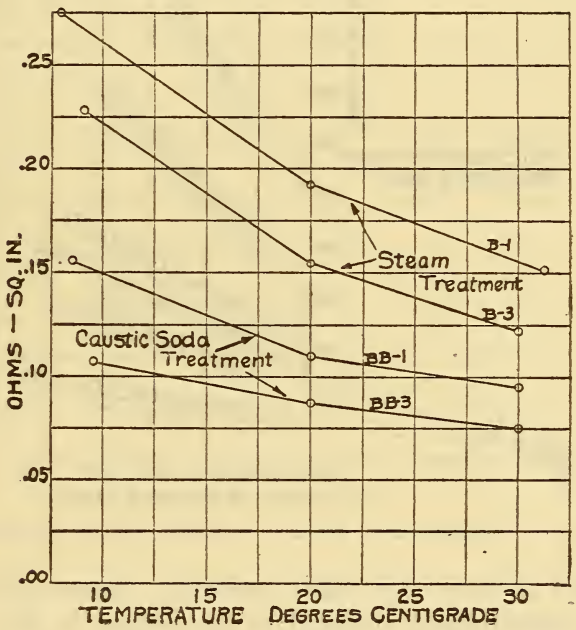

FIG. 7.—*The effect of temperature on the resistance of separators. Specific gravity 1.265*

5. THICKNESS AND METHOD OF CUTTING

The variation of resistance with thickness is shown in Figure 8, which represents the results obtained with separators from manufacturer C. These samples were all of the same pattern (No. 4) but of different thicknesses. Since the resistance of a conducting path is proportional to its length, results similar to those obtained were to be expected. It is probable, however, that the shape of the curves would be affected by the length of time the separators were treated. The curves of Figure 8 suggest that the

steam treatment in the case of the thickest cedar and cypress samples may not have been complete. The curves of Figure 8 when prolonged pass approximately through the origin as they should for separators of zero thickness.

The resistance of rotary-cut separators was higher than for the sawn ones in all cases where comparison could be made between separators which were otherwise identical, with the exception of cypress (Table 5). The rotary-cut separators would

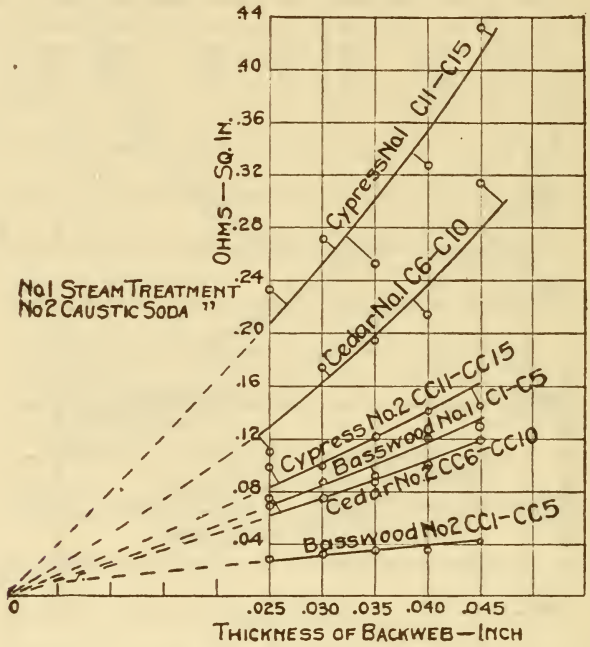

FIG. 8.—*The variation of resistance with thickness of the separators*

be expected to have the higher resistance, because the annular rings are approximately parallel to the surface of the separator.

IV. MECHANICAL STRENGTH

For measuring the mechanical strength of the separators a tensile-strength testing machine was used. The specimens were cut in the form of strips consisting of two ribs and the intervening web. The values given in the accompanying curves and tables are the actual breaking strengths in pounds and represent the mean of several specimens. The breaking strength in tension is used as a measure of the mechanical strength, and all comparisons were made between samples of the same size and pattern.

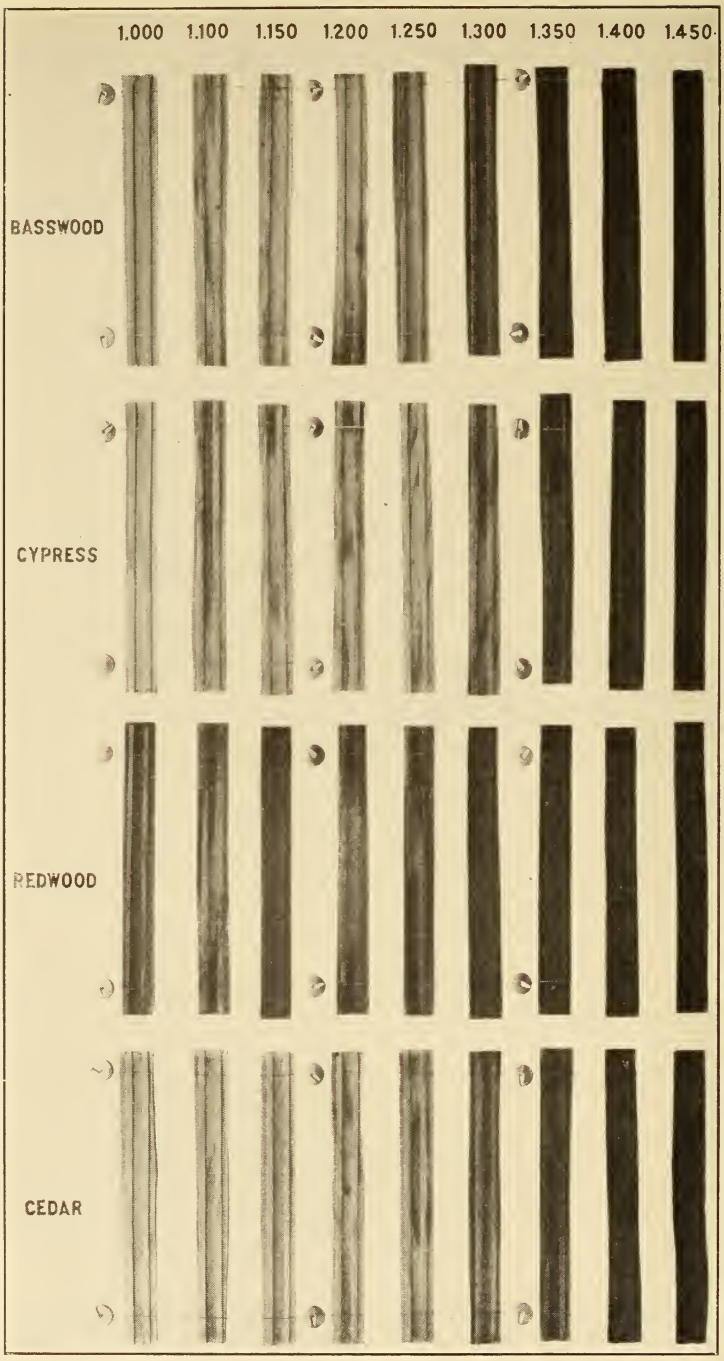

FIG. 10.—*The effect of acid concentration on the wood fiber*

For studying the effect of acid on the wood six narrow strips of each kind of sample from manufacturer B were placed in large test tubes containing acid of different concentrations. One group of these test tubes was kept at a constant temperature of 17° C., and another group at 45° C. The specific gravity of the acid was reduced slightly by the water extracted from the separators. At the end of four weeks two strips were removed from each test tube and broken in the testing machine, and at the end of 21 weeks the remaining four strips were broken.

1. TIME OF IMMERSION

The effect of acid on wood was apparent from the appearance of the wood and the change in its mechanical strength. Since the action of acid on wood is a chemical reaction and tends to destroy

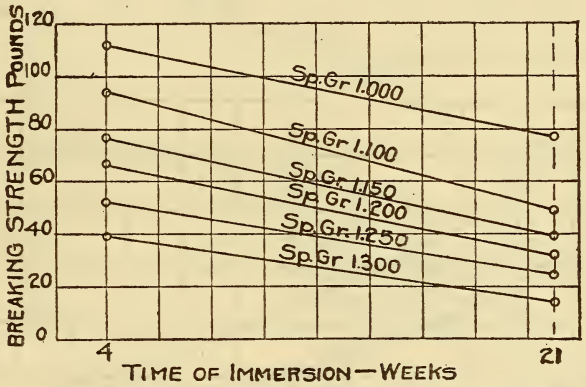

FIG. 9.—*The relation of breaking strength to time of immersion*
Samples of cedar, temperature 45° C.

the cellulose fibers, the extent of the action should be expected to increase with time. This was found to be the case, as is shown in Table 5, for two different specific gravities and by the curves for cedar in Figure 9. The effect of time of immersion seemed to be about the same for all concentrations of acid used; that is, the curves (fig. 9) are approximately parallel.

2. ACID CONCENTRATION

The chemical action of sulphuric acid on wood was found to increase with the concentration, the higher concentrations tending to char the wood. This is a characteristic of the action of sulphuric acid upon organic material. Above a specific gravity of 1.300 the effect became severe, as shown by the appearance of the specimens in Figure 10. The loss in breaking strength during

TABLE 5.—Effect of Time of Immersion on Breaking Strength

[Per cent of loss of breaking strength in tension for specimens in acid based upon the strength of like specimens in water for the same period of time]

Kind of wood	Temperature	Four weeks' immersion					Twenty-one weeks' immersion				
		Water	Acid, specific gravity 1.150	Loss	Acid, specific gravity 1.300	Loss	Water	Acid, specific gravity 1.150	Loss	Acid, specific gravity 1.300	Loss
	°C.			Per cent		Per cent			Per cent		Per cent
Cedar	17	162	113	30	60	63	132	67	49	42	68
Do	45	132	78	41	40	70	78	39	50	15	81
Fir	17	162	93	43	70	57	160	80	50	47	71
Do	45	123	76	38	43	65	110	53	52	25	77
Cypress	17	74	47	37	42	43	60	40	33	26	57
Do	45	70	40	43	38	46	48	25	48	12	75
Redwood	17	118	58	51	32	33	72	23	66	15	79
Do	45	112	44	61	23	80	53	16	70	9	83
Cherry[1]	17	35	37	.....	13	63	30	15	50	3	90
Do[1]	45	27	24	11	18	33	12	5	58	½	58

[1] Samples cross-grained and not uniform.

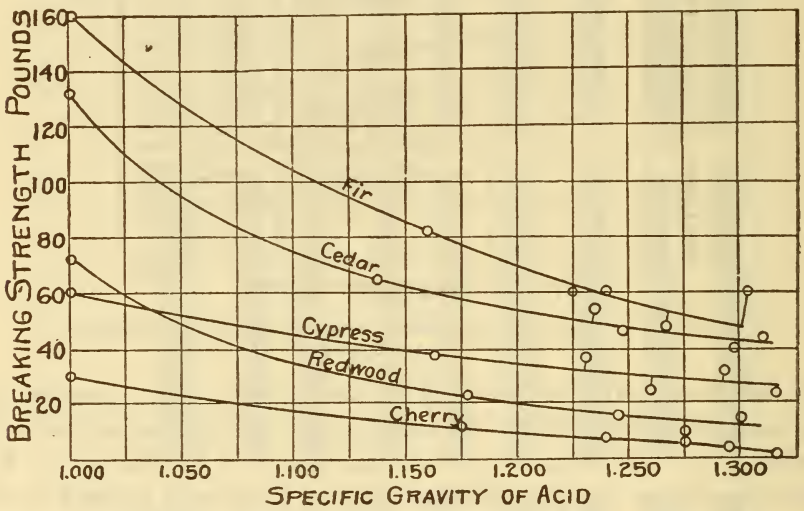

FIG. 11.—*Effect of concentration on breaking strength*

Samples immersed 21 weeks, temperature 17° C.

21 weeks' immersion (fig. 11) amounted to 50 per cent or more and was not greatly different for the different kinds of wood with the exception of cherry, which was almost completely destroyed at the higher concentrations.

3. TEMPERATURE

Chemical action of the acid on wood increases with temperature, as is shown by the curves in Figure 12 for different acid concentrations. Cedar is taken as a typical case. The strength at 45° C. averages about one-half of the strength at 17° C. for all the acid concentrations used.

4. THICKNESS

For obtaining the relation between thickness of back web and breaking strength separators were used having the same pattern

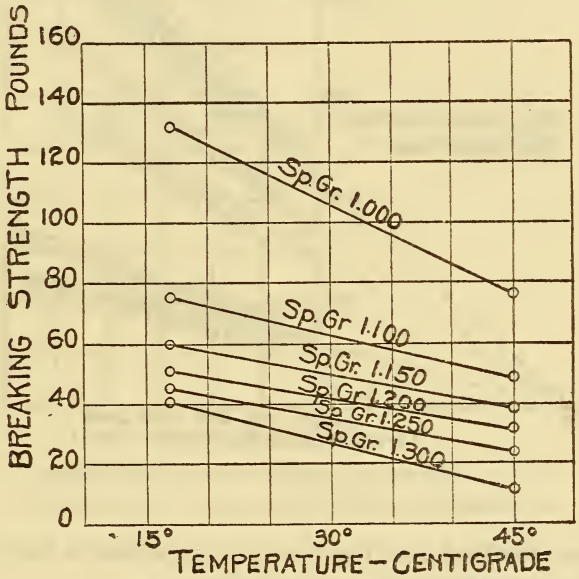

FIG. 12.—*Relation of breaking strength to temperature*
Samples of cedar immersed 21 weeks

but different thicknesses. These samples were obtained from manufacturer C. The breaking strength in tension is proportional to the thickness as shown by the curves in Figure 13. If prolonged, they intersect at zero thickness, as should be expected.

V. SUMMARY

Storage-battery separators of different kinds of wood from three different manufacturers were compared in respect to their electrical resistance, mechanical strength, and resistance to the action of sulphuric acid. Part of the samples were treated by the steam method and part by caustic soda. They were subjected

to immersion for different lengths of time in various concentrations of acid at different temperatures.

It was found that the electrical resistance of a separator, becomes practically constant after about three weeks and is proportional to the resistivity of the acid. The samples treated by the caustic-soda method have about one-half the resistance of those treated

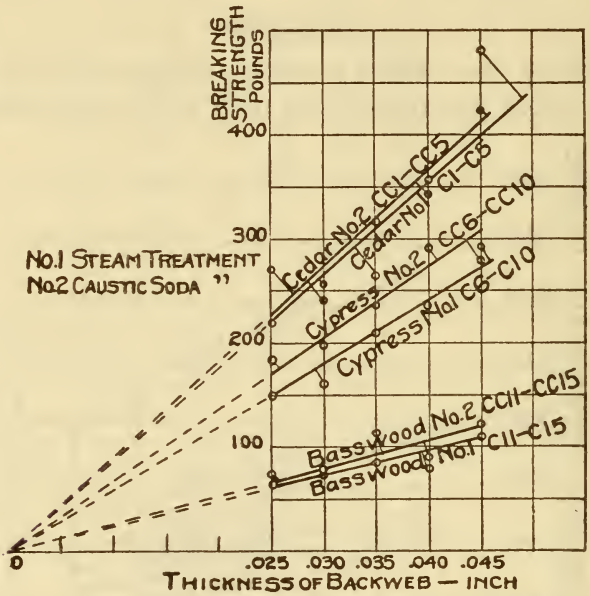

FIG. 13.—*Variation of breaking strength with thickness*

No. 1 samples were treated with steam and No. 2 with caustic soda

by the steam method, and the rotary cut specimens have a slightly higher resistance than the sawn specimens.

The mechanical strength of the wood is reduced by increasing acid concentration, temperature, and time of immersion. Both the mechanical strength and electrical resistance increases in proportion to the thickness of the separator.

WASHINGTON, July 17, 1924.