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THE ACTION OF ACID MINE WATER
ON THE
INSULATION OF ELECTRIC CONDUCTORS
A PRELIMINARY REPORT

BY

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THE ACTION OF ACID MINE WATER ON THE INSULATION OF ELECTRIC CONDUCTORS; A PRELIMINARY REPORT.

By H. H. CLARK and L. C. ILSLEY.

INTRODUCTION.

Moisture and acid are foes of electric insulation and are especially active when combined. In mining work it frequently happens that an electric conductor is exposed to the action of moist air and acid water. This condition, although common to nearly all conductors installed in wet parts of a mine, is especially noticeable in shafts and bore holes through which signal, telephone, or power cables are led under ground. Large quantities of moisture are often present in such places, and in the shafts of coal mines that have several levels the moisture below the first level is sometimes very acidulous. Not all conductors used in mines are insulated, but some of them are, and whenever multiple-conductor cables are used they must, of course, be insulated.

The use of such cables in shafts, bore holes, and even under ground will increase as the use of alternating current increases. At present the practice of consolidating mine power plants, or purchasing power from central stations, seems to be coming into favor, and in either case alternating current will be used for distributing the power. Therefore it seems probable that insulated conductors will be used in mines more extensively in the future than in the past.

It is a matter of common experience that mine water has a harmful action upon the insulation of electric conductors and often so impairs the insulation that shocks may be received from conductors that have previously been considered safe. Sometimes the insulation is completely destroyed, causing bad leakages to the earth and short circuits of multiple-conductor cables.

The Bureau of Mines therefore decided to investigate the action of acid water upon the various materials used to insulate electric conductors in order to determine, if possible, what material is best suited for insulating purposes in mines, thus assuring the continuance of safe conditions. The general plan was to select a number of

insulated conductors and apply acid water to the insulation, making record of the effect produced as determined in various ways. A careful consideration of the subject showed that the investigation would be one of considerable magnitude, and that its undertaking involved the standardization of conditions for whose establishment no data were available. It was therefore decided to make a small preliminary investigation to gain the information necessary to properly organize a larger and more complete series of tests.

This paper reports the results obtained from the preliminary investigation. The bureau is indebted to the Standard Underground Cable Co. and the Western Electric Co. for materials supplied without charge, and the authors of this paper are especially indebted to Mr. Henry W. Fisher, chief engineer of the Standard Underground Cable Co., for valuable suggestions and assistance in organizing the investigation.

GENERAL ORGANIZATION OF THE PRELIMINARY INVESTIGATION.

SPECIFIC PURPOSES.

The purposes of the preliminary investigation were to determine the character of acid water to be used in future tests of this sort; to ascertain the most effective method of applying the water to the insulation in order to determine, for the insulated conductors to be tested, the minimum dimensions that would permit the making of satisfactory observations of the action of the acid water upon the insulation; to discover the best way to prepare and mount for test the insulated conductors to be investigated; to find out something of the acid water resisting qualities of several kinds of insulation; and, finally, to disclose as many as possible of those unforeseen obstacles that always appear during the progress of a new investigation and cause annoying and expensive delays.

SELECTION OF ACID WATER.

It was desired to procure a water of uniform quality that would produce upon electrical insulation an effect equal to or slightly greater than that produced by the most acid mine water that could be obtained.

The collection and analysis of water from a number of mines showed that it was not possible to obtain, even from the same mine, two samples of water that had the same constituents combined in the same proportions. The acidity of mine water changes continually and is greatly affected by the surface rainfall and by other factors beyond the control of the investigators.

Even if a mine produced acid water of a uniform quality it would be difficult, if not impossible, to maintain the uniform quality of the

water while collecting, shipping, and storing it in such quantities as would be necessary for the investigation. It therefore seemed out of the question to use natural mine water in the tests. P. H. Bates, A. C. Fieldner, and F. M. Stanton, chemists of the bureau who assisted in the investigation and analyzed the mine waters that were collected for examination, gave the opinion that the only deleterious constituent of the waters, other than sulphuric acid, was iron sulphate. A water containing iron sulphate and sulphuric acid in any desired proportions could be easily prepared and kept in a satisfactorily uniform condition. It was therefore decided to use in the investigations artificial solutions of this sort, as there seemed to be no doubt that the use of such solutions would give more accurate and consistent results than could be obtained by the use of mine waters of varying qualities and compositions. It was decided to use two solutions, both to contain sulphuric acid in equal amounts, but only one to contain iron sulphate. It was planned to ascertain thus whether the presence of the iron sulphate was a material factor in the destructive action of the water.

APPLICATION OF THE ACID WATER.

It was decided, after conference with the chemists assisting in the investigation, that the most effective way of applying the acid solutions to the insulation under test would be to sprinkle the insulation with the solution at such intervals as would allow the solution time to evaporate between each application.

DIMENSIONS OF CONDUCTORS TESTED.

In order to use to the best advantage the funds and space available it was decided to use the smallest amount of material thought to be consistent with satisfactory results. The thickness of the insulation and the length and diameter of the conductors were specified with this consideration in mind.

MOUNTING CONDUCTORS FOR TEST.

As the measurement of insulation resistance was the principal observation to be made, the conductors were mounted so that no leakage paths could exist around the insulation or across its surface. It was decided to test the effectiveness of sealing both ends of each conductor in a manner later described.

In order to simulate the conditions of actual practice, it was decided to make bends at several points in the conductors. It was decided to mount the conductors in a horizontal position in order to facilitate the application and absorption of the acid solutions.

SELECTION OF INSULATION TO BE TESTED.

The following kinds of insulation were tested: Standard, 30 per cent Para rubber, made in accordance with the specifications of the National Rubber Covered Wire Engineers' Association; standard varnished cambric; varnished cambric treated with a compound designed especially to resist the action of acid; and paper protected with a lead sheath. The rubber and the standard varnished cambric were selected as representing the best practice. The special varnished cambric was selected as offering an opportunity for obtaining data on specially treated tape insulations in general, and on this form of treatment in particular. The lead-sheathed paper-insulated conductors were tested to learn how the acid solutions would affect the lead sheath.

MATERIALS USED AND ARRANGEMENT OF THE TEST.**ACID WATER SOLUTIONS.**

The average amount of free sulphuric acid found by analyzing samples of 16 different mine waters was 492 parts per 1,000,000 (23.68 grains per gallon). The maximum amount of free sulphuric acid found in any sample was 3,662 parts per 1,000,000 (212.49 grains per gallon). It was decided that the artificial waters should contain a little more acid than the strongest mine water, in order to hasten results and have a margin of safety in the matter of acidity.

COMPOSITION OF SOLUTIONS.

A solution was therefore prepared containing 4,500 parts per 1,000,000 (262.35 grains per gallon) of free sulphuric acid. This solution is designated as "solution No. 1." A second solution was prepared containing the same amount of acid and in addition 12,000 parts per 1,000,000 (699.6 grains per gallon) of ferrous sulphate. This amount of ferrous sulphate represents the maximum quantity that the solution would contain without precipitation. As much ferrous sulphate as possible was included in the solution in the hope of distinguishing as clearly as possible whether there was any action on the insulation due to the presence of the sulphate. This solution is designated as "solution No. 2" in this paper.

About 200 liters of water* from the Pittsburgh city mains was placed in each of two barrels and to the water in the first barrel there was added a sufficient quantity of concentrated sulphuric acid to make

* Several analyses of this water made at different times show that it contains no constituents that are not found (usually in much larger proportions) in the mine waters examined by the bureau prior to the beginning of the test.

the solution contain 4,500 parts per 1,000,000 of free sulphuric acid. To the water in the second barrel was added an equal amount of acid and also 12,000 parts per 1,000,000 of ferrous sulphate.

STORAGE OF SOLUTION.

The solutions were stored in wooden barrels and drawn off through wooden spigots. The exposed surface of the stored solutions was covered with a film of oil about one-half inch thick to maintain the solutions in a constant condition. The solutions were analyzed from time to time in order to insure their uniform character, and the solutions as a whole were renewed every three to six weeks, depending upon the daily consumption, which varied during the test. On several occasions chemical analyses were made of the solutions after they had been stored two to six weeks, and each such analysis showed that the character of the solution had not changed appreciably since it was prepared.

INSULATION TESTED.

Samples of four kinds of insulating material were tested as follows: Special varnished cambric, 30 per cent Para rubber, standard varnished cambric, and paper protected by a lead sheath.

SPECIAL VARNISHED CAMBRIC.

The special varnished cambric samples, termed "special samples" and designated by the letter S in this report, consisted of No. 6 Brown & Sharpe gage solid wire, insulated with varnished cambric specially treated to withstand moisture, and protected with a single cotton braid saturated with compound, but not having the smooth, hard finish usually seen on the so-called weatherproof braids. The dimensions of these samples were as follows:

Length of each sample, 50 feet.

Diameter of wire, 0.162 inch.

Thickness of cambric insulation (8 layers), 0.146 inch.

Thickness of single cotton braid, 0.056 inch.

THIRTY PER CENT PARA RUBBER.

The 30 per cent Para rubber samples, termed "rubber samples" and designated by the letter R in this report, consisted of a No. 1/0 (B. & S. gage) solid wire insulated with 30 per cent Para rubber compound in accordance with the specifications of the National Rubber Covered Wire Engineers' Association. The rubber insulation was protected with a single wrapping of tape and a double cotton braid having a weatherproof finish. The dimensions of these samples were as follows:

Length of each sample, 50 feet.

Diameter of wire, 0.325 inch.

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Thickness of rubber insulation, 0.0925 inch.

Thickness of tape outside of rubber, 0.009 inch.

Thickness of inside braid, 0.035 inch.

Thickness of outside braid, 0.033 inch.

STANDARD VARNISHED CAMBRIC.

The standard varnished cambric samples, termed "cambric samples" and designated by the letter C in this report, consisted of No. 6 (B. & S. gage) solid wire, insulated with varnished cambric and protected with a double cotton braid having a weatherproof finish. The dimensions of these samples were as follows:

Length of each sample, 50 feet.

Diameter of wire, 0.162 inch.

Thickness of varnished cambric (11 layers), 0.116 inch.

Thickness of tape next to cambric, 0.006 inch.

Thickness of inside braid, 0.029 inch.

Thickness of outside braid, 0.04 inch.

LEAD-SHEATHED PAPER.

The lead-sheathed paper samples, designated by the letter T in this report, were prepared from a 5-pair, lead-sheathed, paper-insulated telephone cable. The dimensions of these samples were as follows:

Length of each sample, 25 feet.

Thickness of lead sheath, $\frac{3}{8}$ inch.

Size of wire, No. 22 B. & S. gage.

Two layers of paper were wrapped around each conductor, and the core formed from the 10 conductors was also wrapped with manila paper. This telephone cable was tested to ascertain the action of the acid upon the lead sheath. Paper insulation was selected because it would show a high insulation resistance while the sheath was intact, but would show a very low insulation resistance as soon as the slightest hole was made in the lead sheath.

DESIGNATION OF SAMPLES.

Symbols were adopted to designate the samples. They consisted of a figure (1 or 2) to indicate the kind of acid solution used, a letter (C, S, R, or T) to indicate the material with which the sample was insulated, and a figure (1 to 5) to differentiate similar samples tested in the same solution. For example, 1C4 designates sample No. 4 insulated with standard varnished cambric and treated with solution No. 1; 2S2 designates sample No. 2 insulated with special varnished cambric and treated with solution No. 2; 1R5 designates sample No. 5 insulated with 30 per cent Para rubber and treated with solution No. 1.

PREPARATION OF SAMPLES.

All samples were mounted on wooden trays, each of which was 12 feet long, 5 inches deep, and wide enough to accommodate five samples. The ends of each sample were secured as detailed below and the body of the sample was laid along the bottom of the tray. As each sample (excepting the lead-sheathed telephone cable) was 50 feet long, while the trays were but 12 feet long, it was necessary to bend each sample into four parallel sections. Both ends of each sample were brought into a wooden box and the cotton covering was removed from the part of the sample within the box, and the box then filled with a special insulating compound that completely covered one end of each sample, leaving the other end projecting about 1 inch above the surface of the compound. All insulation was removed from the part projecting above the compound so that an electrical connection for testing could be easily made. The form and general arrangement of the samples are shown in figure 1, in

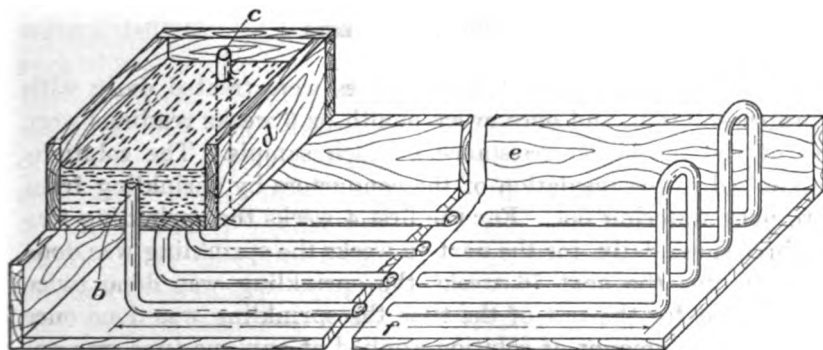


FIGURE 1.—General arrangement of samples in testing trays.

which *e* indicates the tray in which the sample *cb* was mounted; *d* indicates the box in which the ends of the sample were sealed; *a* indicates the insulating compound used for sealing; *b* indicates the dead end of the sample; *c* indicates the end that was exposed for connection to the testing equipment; and *f* indicates the horizontal length of the sample, which when bent was about 12 feet. There were eight 90° bends and three 180° bends in each sample. The lead-sheathed paper-insulated cable was cut into two samples, each 25 feet in length. One end of each sample was sealed and the other was brought through a box filled with insulating compound in the same manner as the other samples were installed. There were in all 32 samples of wire tested—10 insulated with special cambric, 10 insulated with standard cambric, 10 insulated with 30 per cent Para rubber, and 2 insulated with paper covered with a lead sheath. Half

of the samples of each kind of insulation were tested in the plain acid solution No. 1, and the other half were tested in solution No. 2.

The conductors to be tested were placed in two wooden tanks 13 feet 8 inches long by 5 feet 4 inches wide and 6 inches deep. Three trays were placed in each tank, each tray containing five samples of one kind of insulation. One of the trays in each tank also contained a sample of lead-sheathed paper-insulated telephone cable. There were, therefore, a total of 16 samples of insulation in each tank. One end of each tray rested on the bottom of the tank and the other end of the tray was raised about 8 inches. Thus the floor of each tray was inclined so that the water would drain off. The trays were installed in such a manner that they could be lowered into water in the tanks whenever it was desired to take insulation readings or make high-potential tests. The tanks were known as tank No. 1 and tank No. 2. The samples in tank No. 1 were treated with solution No. 1 and the samples in tank No. 2 were treated with solution No. 2.

CHARACTER OF THE TESTS.

Beginning January 7, 1911, the samples were treated daily with the proper solution, and once every month or 6 weeks readings were taken of the insulation resistance of each sample. The solutions were applied to the insulation of the conductors by sprinkling from an ordinary watering pot. For the first 4 weeks the sprinkling was done three times daily, for the next 10 weeks the sprinkling was done once daily, for the next 76 weeks the sprinkling was done twice each day, and for the rest of the time the sprinkling was done once each day. The amount of solution applied at any one time was approximately 0.17 ounce for each linear foot of conductor. In addition to sprinkling, aspirator bottles were arranged so that the solutions could drip slowly upon certain conductors, thereby maintaining a saturated condition of the insulation at one point. One sample in each tray was also embedded in coal dust, in order to simulate a possible underground condition.

Beginning 8 months after the tests were first started, high-potential tests were made upon each cambric, rubber, and special sample shortly after the close of the insulation measurements and before the samples were removed from the water in their respective tanks. A record was kept of the temperature* of the room in which

* The temperature of the room in which the test was made was observed each time the samples were sprinkled with the acid solution. The average room temperature for the entire investigation was 25.3° C. The average temperature for the winter months was 28.4° C. The average temperature for the summer months when no steam heat was used was 24° C. The maximum temperature observed during the investigation was 34.5° C.; the minimum temperature observed was 12° C.

the testing tanks were installed, and during the insulation-resistance readings the temperature of the water was maintained constant. The trays upon which the samples were mounted were lowered into the water in the tanks about 24 hours in advance of the time at which the resistance readings were taken and were usually allowed to remain in the water until after the high-potential tests had been made.

TESTING EQUIPMENT.

INSULATION-RESISTANCE MEASUREMENTS.

The outfit for measuring the resistance of the insulation consisted of a battery and a high-sensibility galvanometer used in conjunction with a lamp and scale, a one-tenth megohm resistance box, an Ayrton shunt, a reversing switch, and a contact key, the four last named being mounted on a hard-rubber base. The rated sensibility of this outfit is shown by the following example: With a battery of 300 volts, a deflection of 1 centimeter could be obtained through a resistance of 96,000 megohms when the galvanometer was 2 meters distant from the scale. With the battery used, the deflection through 50,000 megohms was 1.65 centimeters. The battery consisted of 288 dry cells 5 inches over all in height and $1\frac{1}{4}$ inches in diameter. The cells were installed in a hardwood cabinet.* Each cell was mounted on a hard-rubber insulator, and all connections from one shelf to another were carefully insulated by running the connecting wires through glass tubing. The galvanometer was installed on a concrete pier built especially to eliminate vibration. The distance between the galvanometer and the lamp and scale was approximately 2 meters. All wiring not on the grounded side of the galvanometer circuit was carefully insulated by suspending the wires from glass rods.

The probable error in determining the insulation resistance of the rubber-insulated samples was about 3 per cent, which was sufficiently exact for the purposes of the investigation. The probable error in determining the insulation resistance of the other samples was less than 3 per cent. The statement above refers to the reading of the galvanometer deflection. No approximation can be made of the error in determining the average temperature of the conductors or the error due to electric leakage in the measuring equipment. Great care was used in obtaining and maintaining a constant temperature and well-insulated equipment. It is believed by the authors that the errors due to temperature and current leakage are negligible.

* The cabinet was similar in design to one constructed by Henry W. Fisher, chief engineer of the Standard Underground Cable Co.

HIGH-POTENTIAL TESTING EQUIPMENT.

The high-potential testing equipment consisted of a 5-kilowatt, 30,000-volt testing transformer with an especially calibrated potential transformer for reading the voltage across the high-tension terminals. The voltage variation was obtained by the use of an induction regulator connected in series with the low-tension side of the testing transformer. By means of special windings on the voltmeter and the potential transformer, it was possible to obtain full-scale deflection at either 7,500, 15,000, or 30,000 volts.

METHOD OF TESTING.

MEASUREMENT OF INSULATION RESISTANCE.

The samples under test were submerged in water at least 24 hours prior to the measurement of insulation resistance. The first measurement (taken before beginning treatment) was made at a temperature of 24° C. The next three measurements were made at a temperature as near 24° C. as circumstances allowed. The arrangements for controlling the temperature were not perfected until the fourth measurement after the beginning of treatment. During this measurement and all subsequent ones, the temperature was maintained at 24° C. while the measurements of insulation resistance were being made and for several hours prior thereto. The measurements were made with a battery that gave about 300 volts. Readings were taken after the samples had been electrified for one minute.

HIGH-POTENTIAL TESTS.

The high-potential tests were usually made about 24 hours after the measurements of insulation resistance had been completed and before the samples had been removed from the water. A lead from one terminal of the testing transformer was connected to a copper plate submerged in the water of each testing tank, and a lead from the other terminal of the testing transformer was connected to the exposed end of the conductor to be tested. After these connections had been made, the potential between the terminals of the testing transformer was raised in a few seconds to a predetermined value and maintained at this value for a specified time or until the insulation of the sample broke down.

The first high-potential tests were made on July 28, 1911, after the samples had been treated for 7 months with the acid solutions. The tests were made by impressing 2,000 volts for one minute between the conductor of each sample and the water in which they were submerged. A similar test was made on September 8, 1911. The next

test was made on November 6, 1911, when the potential was raised to 3,000 volts and the duration of each test was increased to five minutes. Every test made thereafter, except the final breakdown tests made on January 17, 1913, was made with 5,000 volts impressed for five minutes.

Power was taken from the 60-cycle circuit used for city lighting in Pittsburgh. An oscillogram taken from this circuit showed the potential wave to be almost a sine curve.

EXAMINATION OF SAMPLES AFTER BREAKDOWN.

After the insulation had broken down as a result of the application of high potential, sections of the samples were inspected, the tensile strength of the cambric tapes and rubber compound was measured by the Bureau of Standards, and some of the cambric tapes were examined with the aid of a microscope. Stretch tests, as prescribed by the National Rubber Covered Wire Engineers' Association, were also made of the rubber compound. In the opinion of the bureau's chemists, it appeared that chemical examination was not capable of affording any definite information as to the extent of the acid penetration, although it was possible to determine qualitatively the acid reaction of the various layers of the samples that were insulated with cambric tape. In addition to the foregoing, the appearance of the samples under test was examined within a few hours after the completion of the high-potential tests. At the end of the two-year treatment measurements were made of the insulation resistance of short lengths of tape from each layer of the covering of the cambric and special samples both before and after treatment. The purpose of this test was to determine whether the solutions had actually changed the conductivity of the insulating material or had merely crept between its layers and thus provided a leakage path for the current. This test is herein termed the "tape test." Finally a fresh sample of each kind of insulation was treated with plain water for 30 days in order to compare the action of plain water with the action of acidulated water. This test is termed the "control test."

RESULTS OF TESTS.

INSULATION RESISTANCE.

The table following gives the results obtained from the periodic measurements of insulation resistance. The values given are the average of the samples under test in each tray. There were five samples in every instance unless the contrary is stated.

Decrease of the insulation resistance of the samples as treatment progressed.

Date of measurement. ^a	Temperature of water.	Insulation resistance in megohms.							
		Rubber.		Standard cambric.		Special cambric.		Lead-sheathed paper. ^b	
		Tank 1.	Tank 2.	Tank 1.	Tank 2.	Tank 1.	Tank 2.	Tank 1.	Tank 2.
1910. Dec. 30.....	24	46,300	49,100	2,400	2,085	1,340	1,490	.....	.....
1911. Feb. 9.....	24	33,400	32,800	1,217	915	405	393	.....	.....
Mar. 11.....	23	30,740	32,040	802	692	383	436	750,000	74,300
Apr. 18.....	24	26,940	29,000	446	387	282	316	1,215,000	63,000
June 6.....	24	21,840	.....	182	.....	153	.....	980,000	59,700
June 7.....	24	.....	22,830	.....	143	.....	166	.....	.....
July 18.....	24	20,540	22,310	93.3	77.9	106.5	112	1,390,000	66,500
Sept. 7.....	24	21,680	23,510	58.1	47.5	89.9	88.1	545,000	74,400
Oct. 25.....	24	21,600	23,320	38.5	29.1	72.0	69.4	865,000	48,300
Dec. 12.....	24	.....	20,440	20.3	17.1	78.5	58.5	690,000	70,000
Dec. 14.....	24	19,190	.....	.....	.....	.....	.....	.....	.....
1912. Jan. 26.....	24	19,060	23,780	13.2	11.9	58.5	52.2	870,000	.....
Mar. 13.....	24	20,300	21,000	9.3	8.5	63.1	46.7	864,000	77,300
May 28.....	24	21,380	19,660	76.0	4.6	45.7	29.5	536,000	67,000
July 24.....	24	21,780	20,540	4.5	3.5	36.2	24.1	752,200	75,300
Sept. 17.....	24	19,680	18,960	3.0	2.7	25.5	18.0	1,386,000	70,600
Nov. 20.....	24	22,380	21,840	3.0	2.0	25.9	17.4	795,200	69,270
1913. Jan. 14.....	24	22,800	22,400	3.6	1.9	42.0	16.5	795,200	67,200

^a Treatment with acid water was begun on January 7, 1911.

^b Only one sample in each tank. This material was not received until the tests of the other samples had been started. The seeming discrepancy in the insulation resistance from month to month is explained by the fact that the resistances were usually too great to be measured with much accuracy without the exercise of more care than the purposes of this particular part of the test demanded. The sample in tank 1 was seemingly more carefully prepared by the manufacturers than the sample in tank 2. This accounts for the difference in insulation resistance.

^c This figure refers only to tank 1. The temperature of tank 2 was 22.6.

^d This figure refers only to standard and special cambric samples. Temperature of rubber samples in tank 1 was 23.75 and in tank 2, 23.3.

^e This figure refers to tank 1. The temperature of tank 2 was 24.2.

^f Average of measurements made on 4 samples.

^g Average of measurements made on 3 samples.

^h Average of measurements made on 2 samples.

ⁱ Reading taken on the only sample left.

HIGH-POTENTIAL TESTS.

The table following gives the dates, conditions, and results of the high-potential tests. On the date of the test, the stated voltage was applied to each sample that had not previously broken down. No high-potential tests were made on the lead-sheathed cable.

High-potential tests made upon samples under test.

Date of test.	Volts applied.	Duration of application.	Designation of samples that broke down.	Time required to produce breakdown.
1911.				
July 28.....	2,000	1 minute.....		
Sept. 8.....	2,000	.....do.....		
Nov. 6.....	3,000	5 minutes.....		
Dec. 15.....	5,000	.....do.....		
1912.				
Jan. 27.....	5,000	.....do.....	1C2	3 minutes 45 seconds.
Mar. 14.....	5,000	.....do.....		
May 29.....	5,000	.....do.....	1C4	3 minutes 15 seconds.
July 25.....	5,000	.....do.....	2C4	30 seconds.
			2C3	(a)
Sept. 20.....	5,000	.....do.....	1C1	2 minutes 30 seconds.
			2C1	3 minutes.
Nov. 25.....	5,000	.....do.....	2C2	Do.
			1C3	30 seconds.
1913.				
Jan. 16.....	5,000	.....do.....	2C5	3 minutes 30 seconds.

* 2C3 broke down before potential could be raised to 5,000 volts. This sample had leaked badly in the previous test but did not break down completely.

On January 16, 1913, tests were made to determine the potential necessary to break down one sample in each tray of the rubber and special samples, neither of which had broken down in any previous test. The table following gives the results obtained:

Results of final high-potential tests made January 16, 1913, of rubber and special samples.

Designation of sample.	Volts applied.	Duration of application.	Sample broke down.
1B1.....	10,000	2 minutes.....	No.
1B1.....	15,000	1 minute.....	Yes.
1R1.....	15,000	2 minutes.....	No.
1R1.....	16,800	Break was instantaneous.....	Yes.
2B1.....	7,500	2 minutes.....	No.
2B1.....	15,000	.....do.....	Yes.
2R1.....	15,000	1 minute 12 seconds.....	Yes.

On October 1 and 15, 1912, samples of the original conductors that had not been treated with the acid solutions were subjected to high-potential tests to determine the potential necessary to break down the insulation. The results of the tests are presented in the table following, in which the samples are given arbitrary designations:

Results of high-potential tests made October 1 and 15, 1912, of samples of insulation that had not been treated with the acid solutions.

Designation of sample.	Volts applied.	Duration of application.	Sample broke down.
Special A a.....	9,000	2 minutes.....	No.
Do.....	18,000	...do.....	No.
Do.....	30,000	5 minutes.....	No.
Do.....	30,000	...do.....	No.
Do.....	30,000	4 minutes 36 seconds.....	Yes.
Special B.....	30,000	5 minutes 49 seconds.....	Yes.
Special C.....	30,000	5 minutes 36 seconds.....	Yes.
Special D.....	30,000	6 minutes 30 seconds.....	Yes.
Cambric A.....	24,900	1 minute 30 seconds.....	Yes.
Cambric B.....	24,600	Broke while raising voltage.....	Yes.
Cambric C.....	25,200	...do.....	Yes.
Cambric D.....	25,500	...do.....	Yes.
Rubber A.....	30,000	5 minutes.....	Yes.
Rubber B.....	30,000	6 minutes 13 seconds.....	Yes.
Rubber C.....	30,000	4 minutes 7 seconds.....	Yes.
Rubber D.....	30,000	3 minutes 41 seconds.....	Yes.

a The tests on this sample were made several minutes apart.

EXTERIOR APPEARANCE OF SAMPLES.

The samples were examined after the completion of each periodical test. The outer appearance of the cambric samples changed very little, only a few cracks developing during the two years of test. The weatherproof braids of the rubber samples began to crack open after about six months of test, and were much cracked and rotted when the test was completed. The appearance of the rubber insulation exposed by the cracking of the coverings did not show any deterioration.

The outer braid of the special samples began to crack open in about a month and was almost totally destroyed by the end of the test. The appearance of the insulating tapes exposed by the cracking of the braid of these special samples did not seem to be greatly affected.

The weatherproof covering appeared to deteriorate most rapidly at those points where the acid solutions evaporated. The first cracks in the covering appeared in a line along the top of the sample. The outer covering of the special samples was not filled with compound as were the coverings of the other samples, and the fibers of the covering produced a capillary action upon the solution, raising it as high as possible, and thus establishing a point where a large proportion of the solution sprinkled upon the sample evaporated. The effect of this action was most evident on the vertical parts of the sample (see Fig. 1) where the continuous evaporation of the solution raised by the fibers made around the sample a circular cut that extended through the outer braid of the sample but not through the first layer of insulation.

The table following states briefly the condition of the outer coverings of the samples as they appeared at the end of each periodic test.

Effect of solution on appearance of exterior of samples.

Date.	Exterior appearance of—					
	Rubber samples.		Cambric samples.		Special samples.	
	Tank 1.	Tank 2.	Tank 1.	Tank 2.	Tank 1.	Tank 2.
Jan. 7, 1911	Good weatherproof finish...		Smooth, glossy, weatherproof finish.		Unfilled braid.	
Feb. 10, 1911	Threadbare.....		do.....		Braid eaten at bends; cracked along top of sample.	Braid eaten at bends; looks ready to crack but is still intact.
Mar. 13, 1911	Extremely threadbare.....		do.....		Long cracks in braid on top of sample.	Few cracks; braid looks weak and crumbly.
Apr. 20, 1911	Weatherproof covering has become very shabby.		Little change.....		Cracks have increased.	Braid decayed and can be brushed off.
June 8, 1911	Cracks have begun to develop.	Cracks have begun to develop, but not so many as in tank 1.	Surface of weatherproof covering appears duller than before.		Cracks in first layer of cambric.	Practically no change.
July 21, 1911	Continuous cracks along the tops of the samples.		Surface of weatherproof covering more threadbare than before.		No change.	
Sept. 9, 1911	No marked change.....		Surface of weatherproof covering has become more threadbare.		Do.	
Oct. 27, 1911	do.....		No marked change.....		Do.	
Dec. 18, 1911	Cracks have increased.		do.....		Do.	
Jan. 29, 1912	Cracks have increased and second covering has broken apart in many places.		Weatherproof covering seems softened.		Do.	
Mar. 15, 1912	Both layers of weatherproof covering on the top of the sample practically destroyed.		Covering has become rotten, but its appearance has not materially changed.		Practically no change.	Braid has become more decayed.
May 30, 1912	do.....		Cracks began to appear....		No change observed.	
July 29, 1912	No change observed.....		No change observed.....		Do.	
Sept. 21, 1912	do.....		do.....		Do.	
Nov. 25, 1912	do.....		do.....		Do.	

MICROSCOPIC EXAMINATION OF SAMPLES.

A microscopic examination of some of the cambric samples was made by Reinhardt Thiessen, assistant chemist of the bureau. After about 18 months of treatment with the acid solutions a piece of 1C4, a piece of 2C4, and a piece of untreated insulation were examined. The treated insulation as compared with the untreated insulation was less readily cut into sections for microscopic examination and showed a darker color under the microscope. The insulating coatings that had been applied to the tapes in the course of their manufacture seemed to have a granular structure in the treated samples, although in the untreated samples the structure of these coatings seemed to be homogenous.

MEASUREMENT OF ACID REACTION.

Tests made by Thiessen also showed that the samples of both special and standard varnished cambric that had been treated with the acid solutions gave pronounced acid reactions even in the inmost layers of tape, whereas samples of the same insulation that had not been treated with the solutions gave weak acid reactions or none at all.

PHYSICAL TESTS OF SAMPLES AFTER BREAKDOWN.

The tensile-strength tests made of the cambric samples indicate that the acid had penetrated as far as the sixth layer of tape, as the breaking strength of the first five layers of the treated samples was less than the breaking strength of the corresponding layers of the untreated samples.

The tensile-strength tests made of the special samples showed practically no difference in the breaking strength of the treated and of the untreated tapes with the exception of the first layer of the treated samples, the strength of which was greatly impaired.

Tests made of the rubber compound used in insulating the rubber samples showed an average tensile strength of 624 pounds per square inch for 8 untreated samples, an average strength of 511 pounds per square inch for 11 samples cut from 1R1, and an average strength of 401 pounds per square inch for 9 samples cut from 2R1. Stretch tests made as specified by the National Rubber Covered Wire Engineers' Association did not produce any trustworthy evidence that the treatment with the acid solutions had any effect on the physical qualities of the rubber insulation. The results of the different stretch tests did not agree, and the greatest deterioration observed was found in a sample of insulation that had not been treated with the acid solutions.

RESULTS OF THE TAPE TEST.

The information obtained from measuring the insulation resistance of short lengths of the cambric and special insulating tapes showed, first, that when first unwound the tapes of the treated samples were much lower in resistance than the tape of the untreated samples; second, that as the tapes were unwrapped the resistance of the inner layers of treated tape was, in general, lower than that of the outer layers; third, that after exposure to the air for several hours the resistance of all treated tapes increased to values comparable with those of the untreated samples; fourth, that the resistance of the outermost layer of tape seemed to be lower than that of the next layer when first unwrapped, and this relation seemed to exist even after the tapes had been exposed to the air for some time, although the inner tapes, which measured much lower than the second layer at the start, finally became as high in resistance as the second layer,

The results seem to indicate that the moisture penetrated all of the layers of tape. This penetration is evidenced by the low resistance of the treated tapes as compared with the resistance of the untreated tapes. The fact that the resistance of the tapes increased so greatly when exposed to air seems to show that the acid had not affected the insulating qualities of the tapes. The fact that the outer tape manifested and retained a notably low resistance seems to indicate that the acid had affected its insulating qualities to some extent. The fact that the resistance of the second layer of tape showed so much higher than the others at the start may have been due to the fact that, being nearer the outside of the windings, it was partly relieved of its moisture before the measurements were made.

To briefly sum up the results: The acid seems to have no effect upon the insulating qualities of the tapes with the exception of the outer layer, but the acid solution penetrated the interstices between the tapes, and thus destroyed their insulating value.

CONTROL TESTS IN UNACIDULATED WATER.

In order to check the results of the tests made with the two acid solutions a 46-foot sample of rubber, a 50-foot sample of standard cambric, and a 12-foot sample* of special cambric were mounted in the same manner as the original samples and for 30 days, beginning February 28, 1913, were sprinkled twice daily with tap water. The initial-resistance readings were made February 25, 1913, at 24° C., after a 24-hour submersion in water.

The results of the test show that the initial resistance of the samples was less than for an equivalent length when the samples were new.

The final resistance readings were taken on April 2, 1913, at 24° C., after a 48-hour submersion in water.

The maximum temperature during the month was 32° C. The minimum temperature was 19° C.

The effect of the tap water as compared with that of the acid solutions is shown by the following table, which gives the percentage of decrease of insulation resistance in the first month of treatment with the tap water and with the two acid solutions:

Decrease of insulation resistance in first 30 days.

	Rubber samples.	Cambric samples.	Special samples.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Tap water.....	36	21	43
Solution No. 1.....	28	50	70
Solution No. 2.....	33	55	73.5

* These samples were the remnants of the material originally obtained for this investigation, since the beginning of which they had been stored in a dry place in a temperature that during the year probably ranged from 15° to 28° C. They had not been treated in any way prior to this test.

This comparison of results seems to indicate that the tap water and the acid solutions had about the same effect on the rubber samples, but that the acid solutions had a greater effect than the tap water on the cambric samples, both standard and special. Both tap water and acid solutions seem to have had more effect upon the special sample than upon the standard samples, but this is probably due to the better weatherproof covering of the standard samples, which delayed the action of both tap water and acid solutions. In the two-year test, after the weatherproof covering had been penetrated by the acid solutions, the insulation resistance of the standard samples became much lower than that of the special samples. The data supplied by the control test are too meager to support more than qualitative conclusions. The plain water undoubtedly acts to impair the insulation. The reasons why it may affect the cambrics is easily seen, but why it affects the rubber is not so clear. The action of the acid solutions is greater than that of the plain water except in the case of the rubber.

DRYING OF TAPE INSULATION.

On the same day that the final measurements were made in the water test several readings were taken upon the original samples that had undergone the two-year treatment and were still in the testing tanks, but had not been treated with either water or acid solutions since January 14, 1913. The readings showed that the insulation resistance of the rubber samples had increased by amounts varying from 4.4 to 15 per cent, whereas the insulation resistance of the standard sample (only one was left) had increased over 300 per cent and the insulation resistance of the special samples had increased by amounts varying from 150 to 550 per cent.

The table on page 16 shows that up to September 17, 1912, the decrease in the resistance of the cambric and special samples had been uniform and of considerable amount, whereas there was little, if any, change during the next two months. During the succeeding two months (nearly) there was little change in tank 2 and an actual increase in tank 1.

The results of the tape test show that the second layer of tape (the first layer was affected by the acid), when first unwrapped, measured higher in insulation resistance than the layers that were nearer the wire, although when exposed to the air for several hours the resistance of all the layers was uniformly high.

The facts stated above seem to indicate that the tape insulation will dry out if no moisture is applied to the insulation and if the atmospheric conditions are favorable. In the first case mentioned no moisture had been applied to the samples for several weeks, although previously they had been sprinkled twice daily. In the second case

mentioned the relative humidity of the air surrounding the samples was decreasing as the cold weather came on. In the third case the second layers of tape would dry out because of their position in the insulating covering. The fact that the outermost layer did not show a similarly high resistance is ascribed to the fact that this layer had been affected by the action of the acid solution.

DISCUSSION OF TEST RESULTS.

COMPARATIVE ACTION OF THE ACID SOLUTIONS.

The results of the tests show little difference between the action of the two solutions. Both solutions had about the same effect upon the cambric and the special samples. The rubber samples that were treated with solution No. 2 did not show as well as the other samples in the tensile-strength tests, but otherwise the effect of the two solutions seemed to be the same.

METHOD OF APPLYING THE SOLUTIONS.

The results of the test seem to indicate that sprinkling the acid solutions upon the samples is the method of application best adapted to hastening the deleterious action of the solutions. This conclusion is based upon the observation that the parts of the samples that were allowed to remain moist all of the time were seemingly not impaired as much as those parts that were alternately wetted and dried. So far as could be discovered neither bedding the samples in coal dust nor letting acid solution drip on them increased the severity of the conditions.

EFFECT OF THE ACID.

Although the acid may have promoted the entrance of moisture between the layers of tape of both the cambric and the special samples, it was not discoverable that the acid had actually affected the tapes beyond the first one or two layers. So far as could be seen the acid had no destructive effect on the rubber insulation or on the lead sheath of the paper-insulated telephone cable.

RELATIVE RESISTING POWER OF THE INSULATIONS TESTED.

The paper-insulated, lead-sheathed, telephone cable having been tested merely to determine the action of the acid on the lead is not considered in the following statements regarding the relative resisting power of the insulations tested.

The rubber insulation undoubtedly withstood better than the cambric and special insulations the treatment accorded to all. The percentage of decrease in insulation resistance was far less in the case of

the rubber samples than in the case of either the cambric or the special samples, and at the end of the test the insulation resistance of the rubber samples was comparatively high (more than 20,000 megohms). The breakdown voltage of the rubber insulation held up well also. The cambric samples were the most affected by the treatment, for although both cambric and special samples decreased in insulation resistance to less than 2 per cent of their original values, the breakdown strength of the special samples was well maintained throughout the test, whereas all but one of the cambric samples broke down on high potential during the test.

CAUSE OF DETERIORATION OF THE SAMPLES.

The insulation resistance of the cambric and the special samples decreased because moisture penetrated between the layers of tape that constituted the insulation of those samples. The data obtained from the control test pointed to this conclusion. The results obtained from measuring the resistance of the various tapes and the evidence of "drying out" that was observed in several tests indicate that moisture was the chief cause of the failure in insulation resistance. The result of the microscopic examination indicates that the presence of acid promoted the entrance of the moisture.

The reason is not so clear for the failure of the rubber insulation. The results of the water test of the rubber samples seem to show that the treatment with pure water decreases the insulation resistance as rapidly as does treatment with acid solutions. Yet it is hard to believe that the deterioration of the rubber was due to the effect of moisture alone, and it seems more reasonable to consider that the rubber became impaired by the combined effect of temperature, exposure to air, and exposure to the action of the acid solution.

SUMMARY OF INFORMATION AVAILABLE FOR FUTURE TESTS.

The principal fruits of the investigation were the data made available for organizing future tests. The method used for mounting and sealing the samples seemed to be a satisfactory one. The action of the solutions was so gradual that more active solutions may be considered in future tests. The effect of plain water was shown to be sufficiently great to warrant in future work a control test treated with water alone. It will also be advisable to make a test of samples exposed to the air but not treated with water or acid solutions. The method of applying the solutions will probably not be changed in future tests, but the electric potential will be continually impressed upon the samples while they are under treatment.

PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

The following Bureau of Mines publications may be obtained free by applying to the Director of the Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls., 4 figs.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 106 pp., 2 pls., 21 figs.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine by G. S. Rice. 1912. 75 pp., 7 pls., 4 figs.

BULLETIN 45. Sand available for filling mine workings in the Northern Anthracite Basin of Pennsylvania, by N. H. Darton. 1912. 33 pp., 8 pls., 5 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls., 7 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 53. Mining and treatment of kaolin and feldspar in the southern Appalachian region, by A. S. Watts. 1913. 171 pp., 8 pls., 8 figs.

BULLETIN 56. First series of coal-dust explosion tests in the experimental mine, by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 62. National mine-rescue and first-aid conference, Pittsburgh, Pa., September 23-26, 1912, by H. M. Wilson. 1913. 74 pp.

BULLETIN 65. Oil and gas wells through workable coal beds; papers and discussions, by G. S. Rice, O. P. Hood, and others. 1913. 101 pp., 1 pl., 11 figs.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp., 11 figs.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl., 5 figs.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 21. The prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp., 1 fig.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

TECHNICAL PAPER 30. Mine-accident prevention at Lake Superior iron mines, by D. E. Woodbridge. 1913. 38 pp., 8 figs.

TECHNICAL PAPER 39. Inflammable gases in mine air, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 2 figs.

TECHNICAL PAPER 40. Metal-mine accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 54 pp.

TECHNICAL PAPER 41. The mining and treatment of lead and zinc ores in the Joplin district, Missouri, by C. A. Wright. 1913. 43 pp., 5 figs.

TECHNICAL PAPER 43. The influence of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 8 figs.

TECHNICAL PAPER 44. Safety electric switches for mines, by H. H. Clark. 1913. 8 pp.

TECHNICAL PAPER 46. Quarry accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 32 pp.

TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 13 pp.

TECHNICAL PAPER 48. Coal-mine accidents in the United States, 1896-1912, with monthly statistics for 1912, compiled by F. W. Horton. 1913. 74 pp., 10 figs.

TECHNICAL PAPER 52. Permissible explosives tested prior to March 1, 1913, by Clarence Hall. 1913. 11 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp., 5 figs.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Hsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 8. First-aid instructions for miners, by M. W. Glasgow, W. A. Raudenbush, and C. O. Roberts. 1913. 65 pp., 46 figs.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.

MINERS' CIRCULAR 11. Accidents from mine cars and locomotives, by L. M. Jones. 1912. 16 pp.

MINERS' CIRCULAR 12. The use and care of miners' safety lamps, by J. W. Paul. 1913. 16 pp., 4 figs.

