DIRECTIONS FOR TEST NO. 14-35-41

SUBJECT: Resistivity of Liquid Aroclors

METHOD: Resistance Measurements between Conductors

Apparatus

Megohm Bridge: General Radio Company Type 544B, AC operated - 90 volts, serial No. 171. This is a direct-current Wheatstone bridge for measuring high resistances, bridge balance being obtained thru use of a vacuum tube voltmeter. Range: 0.1 megohm to 10,000 megohms, covered by a dial and 5-position multiplier switch. A resistance of 1,000,000 megohms can be detected.

Test Electrodes: Two concentric nickel cylinders (or brass, nickel plated) with feet. Obtained from General Electric Company. The inner electrode has outside diameter of 2.8" and height of 3.25", with area of 184 sq. cm. The outer electrode has inside diameter of 3" and like height of 3.25", with area of 198 sq. cm. The distance between electrodes is therefore 0.1 inch or 0.254 cm. By theory the electrode constant, area/length, is 191/0.254 or 752 where 191 is the average area. In practice the cell constant supplied by General Electric Company is used. For the eldctrodes now in use, the cell constant was given as 815.

Glass Plate: Pyrex, about 3-1/2" diameter with concentric grooves to assist in spacing the electrodes. Obtained from General Electric Co.

Oven: Cenco-DeKhotensky drying oven with two holes in back wall for porcelain tubes for lead wires. Holes must avoid oven heating elements which occupy 2" paths vertically and horizontally intersecting at the center of the circular wall.

Lead Wires: Provide two flexible leads to connect the electrodes in oven to the posts of the bridge. The portions exposed to oven temperature are bared and then covered with porcelain beads. Provide also a flexible lead to ground the bridge to a water pipe. Clean the leads, beads, and porcelain tubes periodically.

Assembly of Test Cell

The grooved glass plate is placed in an 800 cc. beaker. The clean electrodes are placed in the grooves of the glass plate with the connector posts directly opposite in order to give the widest possible spacing to reduce surface conductivity. The cylinders should be very close to equidistant. The apparatus should be dried for 2 hours at 100°C. before use.

Heat the sample to be tested to about 110°C. on a hot plate and pour into the electrode assembly until the level of the liquid is 1/4 to 1/2" above the electrodes. Care must be used to make sure that the

lip of the container, from which the liquid is poured, is clean. Tilt the beaker in such manner that all air bubbles in the Aroclor will rise to the surface.

Air cool to 103-104°C. then without removing thermometer, transfer to the oven which is maintained at 100°C. and connect the electrodes to the two flexible wires which lead to the megohm bridge. When the Aroclor comes to temperature (100°C.), remove thermometer, check centering of electrodes, and procede to measurements.

Measurement with Megohm Bridge

Connect the two lead wires to the megohm bridge with the lead from the outer electrode to the LOW unknown post of the bridge; the inner electrode to the "+" unknown post. Connect the GROUND post on the left side to a water pipe. Swing the spring connector, pivoted on the "G" post, to the LOW post. Connect the attachment cord to the 110 V power supply.

With the Aroclor at 100°C., turn the control knob (CHECK-OPERATE-CHARGE) to the CHECK position. Throw all 3 switches at the rear of the Panel to ON. After 2 minutes bring the galvanometer pointer to zero by means of the ZERO ADJUST knob.

Then turn the control knob to CHARGE for one minute. Turn the knob to OPERATE and return the galvanometer pointer to zero by adjustment of the MULTIPLY BY switch and the megohm dial. Read after one minute. Repeat the CHARGE and OPERATE positions for verification.

The resistivity of the Aroclor is the product of the "multiply by" reading times the dial reading times the electrode constant. Report in units of 10^9 ohm/cm., rounded off to two significant figures.

Example:

"Multiply by" reading : 100
Megohm dial reading 5.4
Electrode Constant 815
Resistivity = 100 x 5.4 x 815
= 4.4×10^5 megohms/cm
= 440×10^9 ohm/cm.

Values for resistivity are qualified by designation of temperature and voltage. These are 100°C. and 90 volts for the test above. Like conditions are used at Plant B. General Electric Company determines resistivity at 100°C., 500 volts D.C.

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Care of Apparatus

The "Operating Instructions", General Radio Form 458-B, which accompany the megohm bridge, recite details of installation, measurements, uses, and construction, illustrated by figures and circuit and wiring diagrams. No attempt is made to reproduce such information here. The operator should acquaint himself with the contents of the G.R. manual and refer to it for maintenance of tubes and parts. When not in use the megohm bridge should be closed and stored in cabinet.

For the removal of Aroclor from electrodes and glassware, a series of covered jars is maintained containing 1 gallon or more of cleaning fluid to a depth of 5" or more. The first 3 jars contain "motosolve" – a mixture of 2 parts mineral spirits and 1 part carbon tetrashloride. The last jar contains pure carbon tetrachloride for a final wash. As the solutions become spent the first wash is discarded and replaced with the second wash, others in turn are moved up, the final wash being used to prepare the Motosolve.

To Clean the Test Cell: Pour out the Aroclor upon removing from oven at 100°C. Let drain for a few minutes. Rinse once in beaker with a little Motosolve which is discarded. While still warm, immerse parts in the first Motosolve wash, dipping in and out several times. Repeat in the second wash using brush over all surfaces. Continue with third Motosolve wash and final wash with pure carbon tetrachloride. Inspect carefully. Dry in oven at 100°C. for 1 hour. Store under bell jar until used. Dry again before use.

If the electrodes show any tarnish, polish them with a paste of rouge on a soft cloth. Clean the glassware as necessary with warm chromic acid solution ($K^2Cr^2O^7 + H^2SO^4$). Refer to General Electric Company methods H-3992863 and H-3984092 for other precautions in cleaning electrodes and glassware.

Calibration and Reproducibility

A reference sample of Aroclor 1254 should be maintained for checking purposes. Resistivity of this sample should be determined semi-monthly or whenever abnormal values are encountered in testing production. Before one reference sample is exhausted another sample should be obtained in order that a number of simultaneous determinations may be made upon the old and new samples.

For a rough check on the condition of the bridge, one or more cartridge-type resistances of known approximate value should be kept on hand for periodic or emergency verification of the meter itself.

Prior to each test, General Electric proscribes checking the electrodes with a standard Aroclor or oil for resistivity value. Agreement with expected value within 20% is necessary before proceding. At least two samples of the Aroclor under examination are tested. These must show agreement within 20%.

Effect of Variables

1. Bridge readings will vary depending upon the time elapsed after closing the circuit switch. The current flowing immediately after closing the switch is greater than after the switch has been in for several minutes. Conforming to common practice, one minute is allowed for "electrification" before reading the bridge meter.

2. The resistivity of Aroclors is lowered by the presence of polar impurities such as ferric chloride or hydrochloric acid. These polar impurities affect the resistivity to a greater extent in the more liquid Aroclors than in the viscous Aroclors (Ref: H.B. Glass).

3. Treatment with Fullers earth has the effect of increasing the resistivity. A chart illustrating time of treatment versus resistivity and power factor has been prepared by the General Electric Company - their 1941 methods.

4. Because the resistivity may vary with the time of heating at the test temperature, 100°C., the assembly and heating of the test cell should be uniformly performed as described.

5. Conforming to General Electric specifications, the resistivity is measured at 100°C. The usual effect of temperature on resistivity is that if the dielectric contains moisture, the application of heat will reduce the moisture content and simultaneously increase the resistivity. In the case of a thoroughly dry dielectric, however, increase in temperature usually has the reverse effect. Prolonged heating of a dielectric, if in excess of safe or conservation working temperature, is injurious and tends to hasten the breakdown of the material by decomposition or chemical change. The General Electric Company specifies that Aroclor 1254 after heating at 100°C. for 96 hours at 100°C. shall show no loss in resistivity.

6. The resistivity of a dielectric with alternating currents is usually less than with continuous currents and decreases progressively as a rule with increase in frequency owing to dielectric energy losses.

7. Utmost cleanliness of all apparatus - beakers, containers, electrodes, thermometer, etc. - coming in contact with the Aroclor is necessary to prevent contamination.

Definitions

Resistance (symbol R): Obstruction to electric flow. The ratio of voltage (E) to current (I) in a conductor or closed circuit. (R = E/I. Ohm's Law). The practical unit of resistance is the ohm.

Electrical Resistivities: The current which flows between two conductors insulated from each other by a dielectric is made up of two components (1) that which flows thru' the dielectric itself and (2) that which flows through a surface film of moisture or other semi-

conducting material (oil, dust, or foreign matter). These components are designated respectively as "volume resistivity" and as "surface resistivity".

Volume Resistivity: Symbol ρ (Greek letter "rho".) Also called specific resistance. Defined as the resistance between two opposite faces of a unit cube of the substance. $\rho = RA/L$ where A is cross-sectional area and L is length of the current path thru the substance. The practical unit of resistivity is the ohm-centimeter (ohm-cm.). The resistivity of Aroclors is reported in multiples of 10^9 ohm-cm.

A volume resistivity of 740×10^9 ohm-cm is equivalent to saying that the resistance offered by the substance between two opposed parallel faces of 1 sq. cm. each, placed 1 cm. apart is 740×10^9 ohms. Following the practice of the General Electric Company, resistivity is measured with the substance under test (Aroclor at 100°C. "Resistivity" as applied to Aroclors always refers to volume resistivity.

Surface Resistivity: (symbol S, Greek letter "Sigma") is defined as the resistance between two opposite edges of a square surface film. The practical unit is the ohm-cm (between opposite edges of a film 1 cm. square) $S = Rb/l$ where R is resistance of a rectangle of film of length l and breadth b.

Measurements of surface resistivity are applied to solid dielectrics rather than to liquid. For most materials the surface resistivity is much lower than the volume resistivity. Atmospheric humidity conditions at time of measuring may frequently greatly alter the surface resistivity.

Resistivity of Various Dielectrics

Reference: Standard Hand-book for Electrical Engineers.
Coursey; Electrical Condensers.

Dielectric	Resistivity in ohm-cm.
SOLIDS	
Paraffin	1 to 10000 x 10^{15}
Fused Quartz (ordinary temp.)	0.1 to 10000 x 10^{15}
Mica, Madras or Bengal	10 to 130 x 10^{12}
Mica, Canada	0.44 to 22 x 10^{12}
Glass (ordinary temp.)	10 to 10000 x 10^{12}
Rubber	100 x 10000 x 10^{12}
Bakelite	0.5 to 3 x 10^{12}
Unglazed Porcelain (ordinary temp.)	100 to 1000 x 10^{12}
Marble	0.1 to 10 x 10^{9}
LIQUIDS	
Transformer Oil A	490 x 10^{9}
Transformer Oil B	3100 x 10^{9}
Pratts Astral (kerosene)	470000 x 10^{9}
Castor Oil	30000 x 10^{9}
Ethyl Alcohol	3.3 x 10^{5}
Linseed Oil	50 x 10^{9}
Olive Oil	1000 x 10^{9}
Water, Distilled	70 x 10^{9}
Arocler 1254 (100°C., 500 V.)	100 to 800 x 10^{9}

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