THESIS

The Megger as a Means of
Testing Transformer Oil.

by

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It is the purpose of this thesis to discuss the importance of, and methods commonly used in, testing transformer oil, to give the results and methods of some experiments on the insulation resistance of transformer oil using the megger as the measuring apparatus, to show the relation of dielectric tests on oils to insulation resistance tests, and to give conclusions derived from the experiments.

Modern transformer design tends toward greater dependence on oil for insulation and less on mica and other mechanically strong types of insulation. At the present time the use of oil for the higher-voltage transformers is considered absolutely essential, and a very large proportion of the low-voltage transformers of large size are also oil-insulated.

The oils in use at the present time for insulating purposes are obtained by fractional distillation of crude petroleum. To be suitable for transformer insulation and cooling, the oil should have a low viscosity over the range of temperature through which the transformer may have to operate, because the oil must readily carry the heat from the transformer to the case or cooling coils, it must be free from moisture, acid, alkali, sulphur, or other materials which might impair the insulation of the transformer, and it must also have as high a flash point as is consistent with low viscosity. The oil must not only be of such consistency that it will circulate freely and so carry heat from the sources where it is generated to external cooling surfaces, but it must also be able to stand voltage stresses. Not only is a high disruptive strength essential, but a high insulation resistance is also desirable. The failure to meet these conditions means the failure of the transformer in which the oil is used.

The method commonly employed in testing the insulation resistance of transformer oil is one of substitution. A standard resistance connected in series with a D'Arsonval galvanometer is connected across a direct-current source of e.m.f. of about 500 volts and the deflection of the galvanometer noted. From the deflection of the galvanometer, with the unknown resistance connected in place of the standard resistance, the amount of unknown resistance is determined. This method at the best is long and tedious and requires apparatus not readily portable.

The usual test that is given transformer oil before it is put into the transformer, and at frequent intervals thereafter, is one for dielectric strength. The test consists in immersing a spark gap (usually spheres or flat disks) in the oil, the gap being set at a known distance, usually 0.15 or 0.2 of an inch, and gradually raising the potential until rupture of the oil occurs.

To the writer's knowledge no tests on the insulation resistance qualities of transformer oil, using the megger as the resistance measuring instrument, have ever been carried on. The megger is a readily portable instrument of the galvanometer type. It is used principally in measuring high resistances where great accuracy is not required. The machine consists essentially of a small d-c generator and a special form of pivoted galvanometer, consisting of a permanent magnet, a soft iron core, a current coil and two pressure coils. These three coils are rigidly attached at a fixed angular distance apart to the shaft which carries the pointer. The generator and galvanometer are mounted in a single box provided with two binding posts for connecting the unknown resistance and a handle for turning the armature of the generator by hand. To determine the resistance of a circuit it is only necessary to set the megger down on a fairly level base, connect the circuit wires to the line and earth terminals, and give the generator handle half a dozen rapid turns, when the pointer comes to rest and indicates the resistance of the circuit in megohms; whence the name - megger.

The auxiliary apparatus used in these tests were two spark gaps, one consisting of two flat disks 0.5 of an inch in diameter, set at a distance of 0.2 of an inch for testing the disruptive strength, and the other consisting of two hollow spheres 3 inches in diameter for testing the insulation resistance of the oil.

The oil sample bottles were given a rigorous treatment to be absolutely sure that they contained no moisture or dirt before they were filled with the oil to be tested. The bottles were first cleaned with a weak solution of hydrofluoric acid and the residue left by the acid rinsed out with high grade gasoline. They were then placed on drying racks, and heated air, which had been passed through sodium-carbonate to remove all moisture, was forced into them. When thoroughly dry they were placed on racks, and air at room temperature,and free from moisture, was forced into them. When the bottles reached room temperature they were tightly corked and dipped into melted parafine, making an air tight seal.

Care must be taken to have the electrodes free from dust or particles of cotton fibre before performing the tests. The importance of this became evident when it was found that the method of polishing the electrodes had a great effect both on the dielectric strength and the insulation resistance. After polishing with a cotton cloth, which usually leaves particles of cotton fibre on the electrodes, the puncture voltage was reduced to about one-half the true value of the dielectric strength of the oil. The insulation resistance was still more affected, due to the shorter distance between the electrodes. In order to be sure that the vessel and the electrodes were perfectly clean the following method was used: The polished electrodes were washed while immersed in the oil; they were then taken out and the vessel was washed by stirring up the oil in it. This process was repeated several times, using clean oil for each operation.

The oil used in these tests was what is commonly known as "high flash transformer oil." The following characteristics were found upon analysis: specific gravite - .855 at 22°C; viscosity - 3.44 at 24°C; flash point - 165.5°C; burning point 184.5°C.

Effect of Temperature.

The insulation resistance of oil varies greatly with changes in temperature. A slight increase in temperature produces a comparatively large decrease in the insulation resistance. At ordinary temperatures the specific resistance is so high as to render its determination exceedingly difficult. A test was made on the oil with varying degrees of heat and a curve plotted from the results obtained. This curve shows clearly the decided effect of heat on the insulation resistance. The temperature must be taken into account in any test on the insulation resistance of transformer oil. A test was also made of the dielectric strength of oil with increasing degrees of heat. As is shown in the results (curve sheet No. 2) the dielectric strength of oil does not vary greatly with slight changes in temperature.

Effect of Moisture.

Transformer oil, as far as the dielectric strength and especially the insulation resistance is concerned, is extremely sensitive to moisture. Shipment of oil in either tank cars or steel drums introduces the possibility of moisture or other foreign substances entering the oil. Some of the moisture may settle to the bottom, where it can be gotten rid of by simply drawing off a limited quantity of oil. A certain percentage will however be retained and kept in circulation. From the curves it is seen that even 0.04 of one percent reduces the dielectric strength to one-half and the insulation resistance to one-seventh of the original value. It is evident from these tests that the importance of dry oil cannot be overestimated.

The following methods were used in testing for the effect of moisture: As has been shown in the tests on the effect of temperature on the insulation resistance of transformer oil, a slight change in temperature makes quite an appreciable change in the insulation resistance, therefore it was thought advisable to make one test holding the temperature constant at room temperature, or 20°C., and another holding the temperature constant at 55°C., the ordinary working temperature of most transformers. Oil which was known to be perfectly dry was given a dielectric test, withstanding a potential of 65,000 volts between two polished brass balls set at a distance of 0.2 of an inch apart, before breaking down. The test sample was then placed in the receptacle containing the hollow spheres electrodes and the megger connected to the gap. The gap was then adjusted until the megger indicated 5000 megohms, the highest reading for which it was calibrated. Water was then added in the proportion of one part of water to 10,000 parts of oil by volume. The mixture of oil and water was thoroughly emulsified and then allowed to stand until all bubbles had disappeared. It was then again subjected to the two tests as outlined above. Tests were continued with increasing proportions of moisture until fairly constant results were obtained, indicating that the oil was completely saturated. The results of these tests indicate that the megger detects moisture in the oil much more readily than the dielectric tester.

Conclusions.

The field for which the megger test is best adapted is power plants, sub-stations, etc., where an oil laboratory containing apparatus for the dielectric test is not at hand. A fair indication of the condition of the transformer oil could be obtained by subjecting it to a megger test. If the oil "meggered" over 3000 megohms, at 55°C between 3 inch sphere electrodes set at 0.04 of an inch apart, corresponding to a puncture voltage of over 45 kilovolts, the oil would be suitable for use in the transformers. Oil which came under this value would either have to be passed through the filter press or taken to the laboratory for a complete analysis.

As to the relation between insulation resistance and dielectric strength, the results of these experiments show that the insulation resistance of an oil is not an indication of its dielectric strength unless the temperature is also taken into consideration.

Owing to the number of variables which may creep into the work, the difficulties in carrying on a study of this kind are great. It was found very difficult to duplicate results even with apparently identical conditions. This applied to both the dielectric and insulation resistance tests.

Great care must be used in measuring the distance between the electrodes in the insulation resistance tests, as this distance is very small and is one of the controlling factors in the test.

A great number of tests were necessary to obtain reliable figures, and curves as reproduced in this thesis were plotted from average values.

Effect of Temperature On the Insulation Resistance Of Transformer Oil.

Oil tested: Specific gravity - 0.855 at 22°C. Viscosity - 3.44 at 24°C. Flash point - 165.5°C. Burning point - 184.5°C.

Test No. 1.

Observation No.	Temperature °C	Resistance Megohms.	Average Resistance Megohms.
1.	50	5000	
2.	50	5000	5000
3.	55	4600	
4.	55	4400	4500
5.	60	3100	
6.	60	3300	3200
7.	70	2350	
8.	70	2300	2325
9.	80	1600	
10.	80	1600	1600
11.	90	900	
12.	90	1000	950
13.	100	600	
14.	100	700	650
15.	110	425	
16.	110	425	425
17.	120	300	
18.	120	250	275

Effect of Temperature

On the Dielectric Strength

Of Transformer Oil.

Oil tested: Dry oil, same as in Test No. 1.

Test No. 2.

Observation No.	Temperature °C	Kilovolts	Aver. Kilovolts
1.	20	60	
2.	20	60	60
3.	30	60.5	
4.	30	60.5	60.5
5.	40	60.6	
6.	40	61.4	61
7.	50	61.4	
8.	50	61.6	61.5
9.	60	62	
10.	60	62	62
11.	70	62.5	
12.	70	62.5	62.5
13.	80	63	
14.	80	63	63
15.	90	63.2	
16.	90	63.6	63.4
17.	100	64.	
18.	100	64.	64

Test No. 2. continued.

Observation No.	Temperature °C.	Kilovolts	Aver. Kilovolts.
19.	110	64.6	
20.	110	64.4	64.5
21.	120	65	
22.	120	65	65

Effect of Moisture

On the Insulation Resistance

of Transformer Oil.

Oil tested same as in test No. 1. Temperature of Oil- 20°C.

Test No. 3.

Observation No.	Water-parts in 10,000 by vol.	Resistance Megohms	Av. Resistance Megohms
1.	0.00	5000	
2.	0.00	5000	5000
3.	0.05	3000	
4.	0.05	3000	3000
5.	0.25	1400	
6.	0.25	1300	1350
7.	0.5	600	
8.	0.5	550	575
9.	1.	280	
10.	1.	320	300
11.	1.5	250	
12.	1.5	270	260
13.	2	260	
14.	2	260	260
15.	2.5	235	
16.	2.5	245	240
17.	3.	225	
18.	3,	225	225

Test No. 3, continued.

Observation No.	Water-parts in 10,000 by vol.	Resistance Megohms	Av. Resistance Megohms
19.	3.5	200	
20.	3.5	200	200
21.	4.0	190	
22.	4.0	170	185
23.	4.5	185	
24.	4.5	185	185
25.	5.0	150	
26.	5.0	150	150

Effect of Moisture

On the Dielectric Strength

of Transformer Oil.

Oil tested same as in Test No. 1. Temperature of oil - 20° C.

Test No. 4.

Observation No.	Water parts in 10,000 by vol.	Kilovolts	Av. Kilovolts.
1.	0.0	65	
2.	0.0	65	65
3.	0.05	50	
4.	0.05	50	50
5.	0.17	35	
6.	0.17	35	35
7.	0.42	25	
8.	0.42	23	24
9.	0.6	22	
10.	0.6	22	22
11.	0.8	20	
12.	0.8	19.4	19.7
13.	1	19.0	
14.	1	17.4	18.2
15.	2	15.5	
16.	2	15.9	15.7
17.	3	14.	
18.	3	14.50	14.25

Test No. 4 continued.

Observation No.	Water parts in 10,000 by vol.	Kilovolts	Av. Kilovolts
19.	4	13	
20.	4	13	13
21.	5	12	
22.	5	12	12

Effect of Moisture

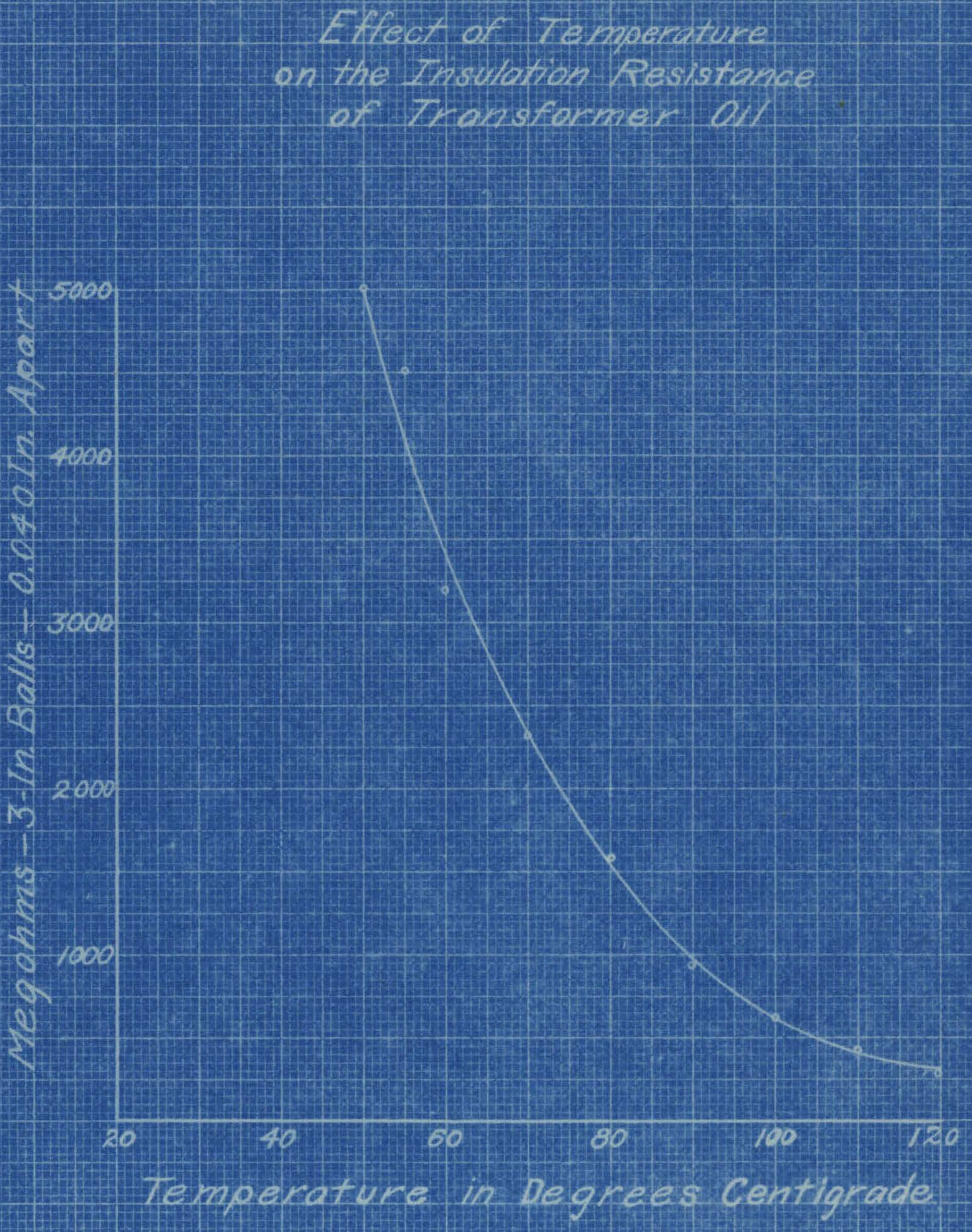
On the Insulation Resistance

of Transformer Oil.

Oil tested same as in Test No. 1. Temperature of oil - 55°C.

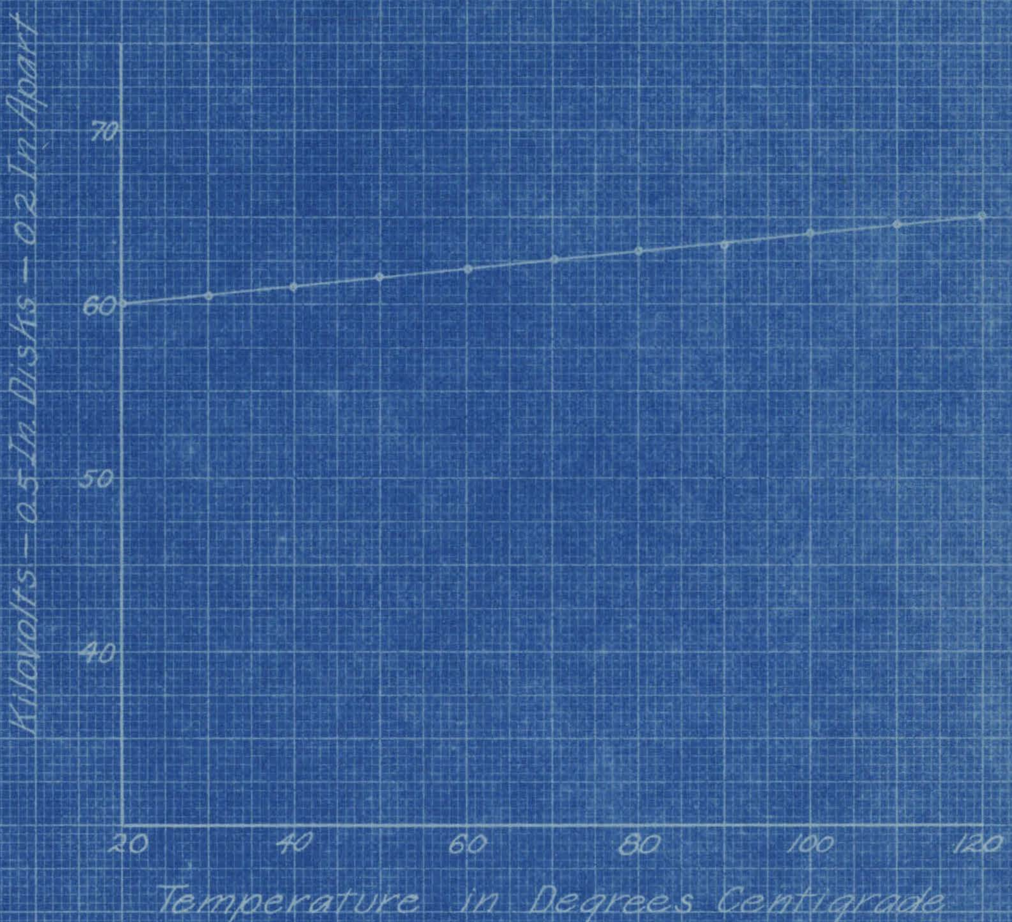
Test No. 5.

Observation No.	Water parts in 10,000 by vol.	Resistance Megohms	Aver. Resistance Megohms
1.	0	5000	
2.	0	5000	5000
3.	0.1	3100	
4.	0.1	3100	3100
5.	0.25	1000	
6.	0.25	11000	1000
7.	0.4	500	
8.	0.4	500	500
9.	1.	260	
10.	1	240	250
11.	2	230	
12.	2	220	225
13.	3	165	
14.	3	175	170
15.	4	150	
16.	4	150	150
17.	5	125	
18.	5	125	125


Effect of Temperature
on the Insulation Resistance
of Transformer Oil
Megohms — 3-In Balls — 0.040 In Apart
5000
4000
3000
2000
1000
20
40
60
80
100
120
Temperature in Degrees Centigrade

Curve sheet No. 2

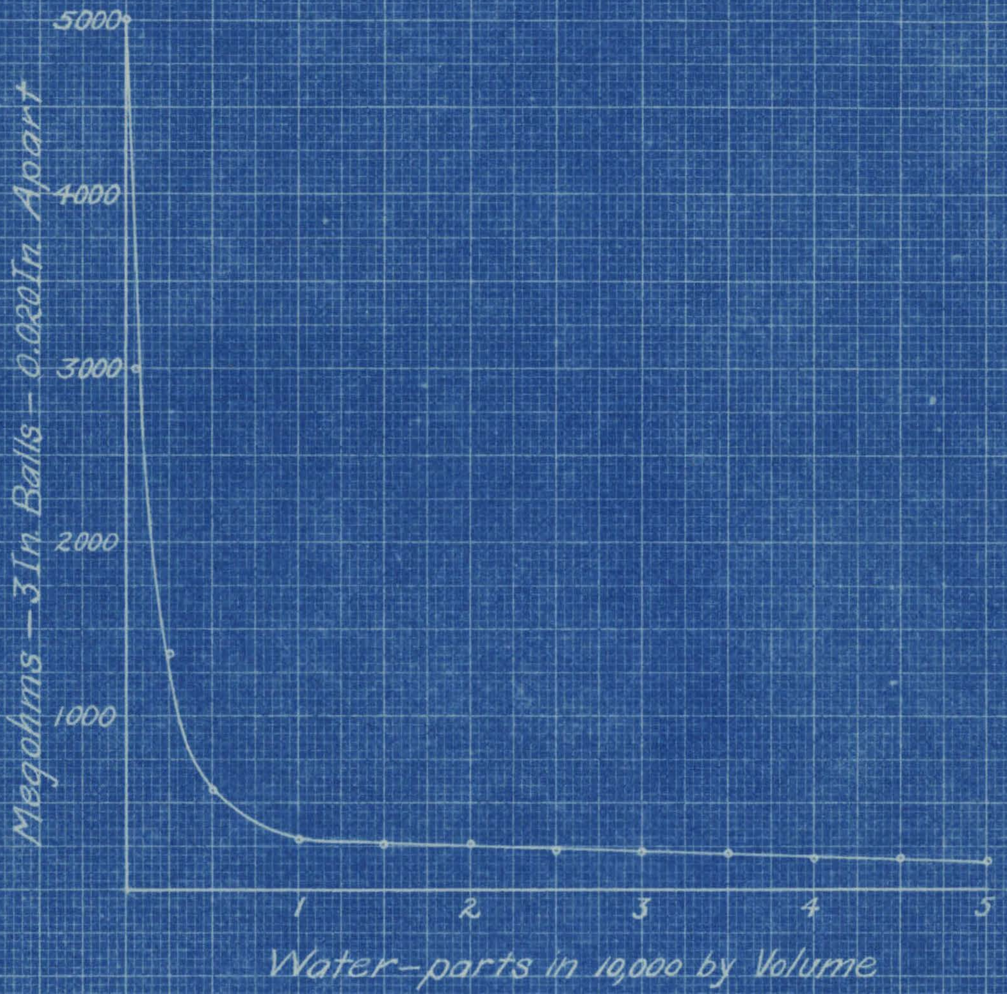
Effect of Temperature
on the Dielectric Strength
of Transformer Oil



Curve sheet No. 3

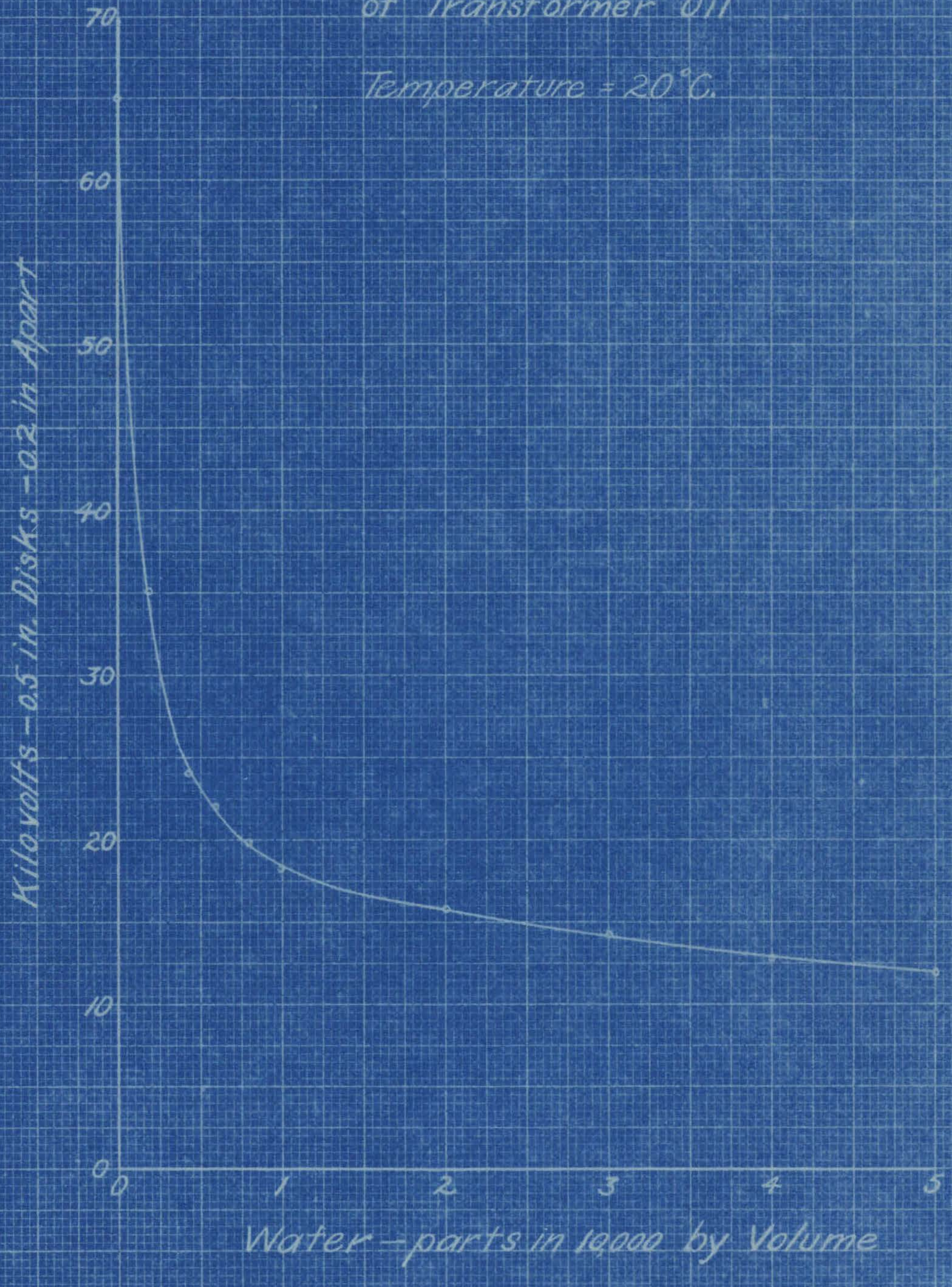
Effect of Moisture on the Insulation Resistance of Transformer Oil

Temperature = 20°C.



Effect of Moisture
on the Dielectric Strength
of Transformer Oil

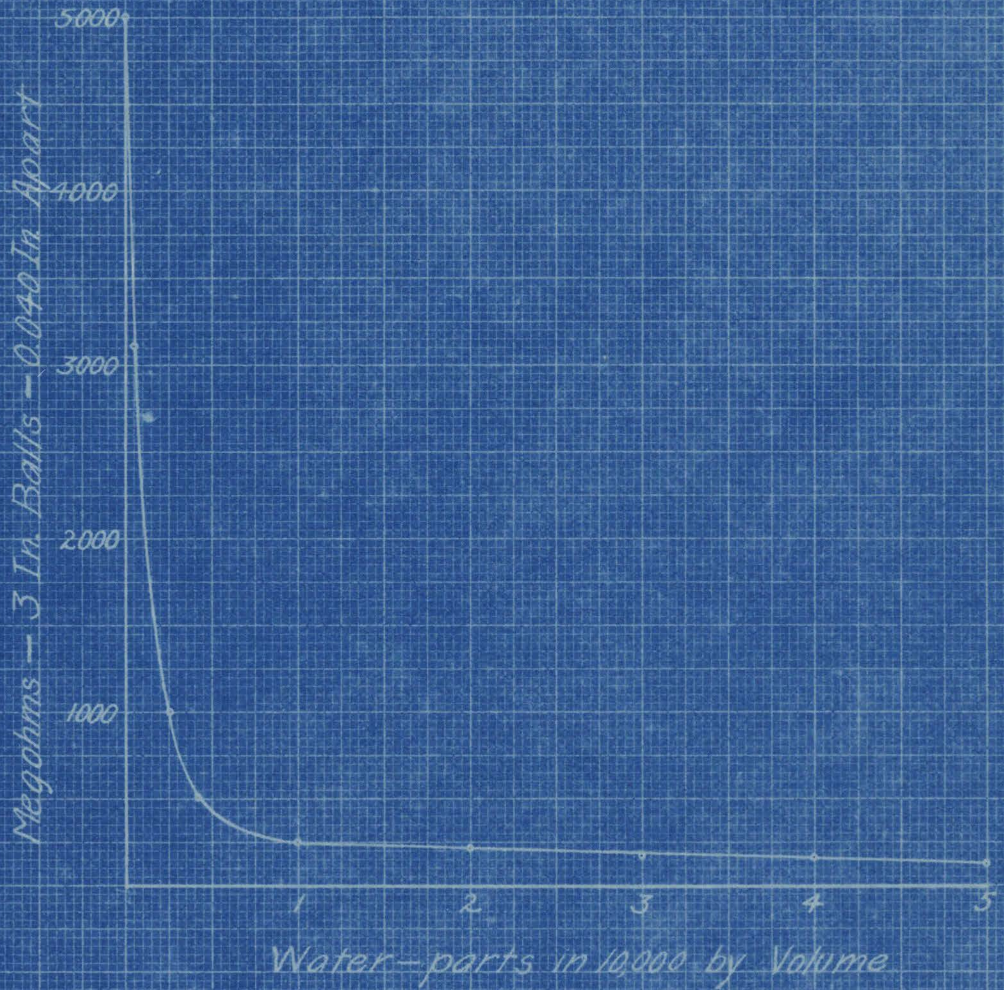
Temperature = 20°C.



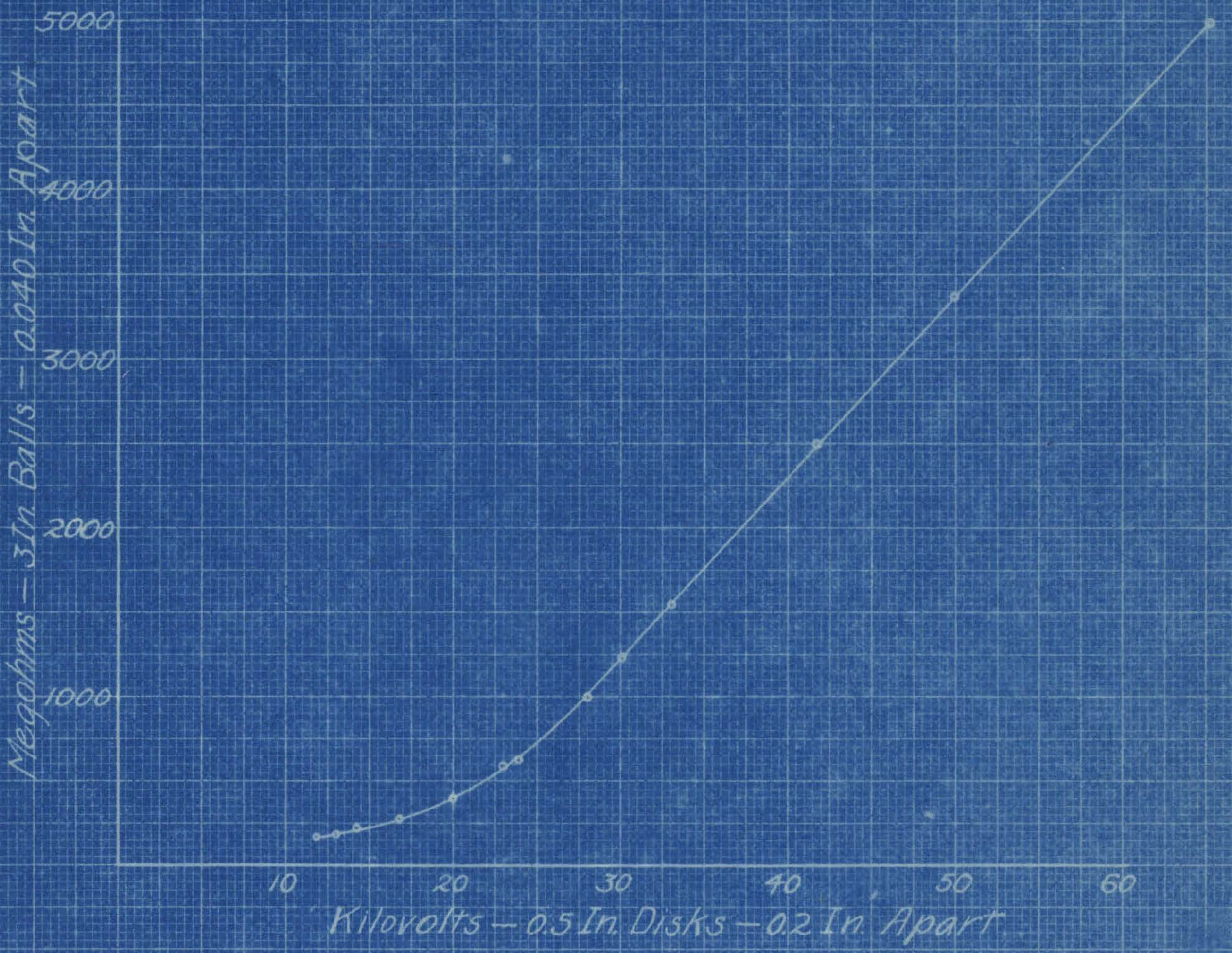
Curve sheet No. 5

Effect of Moisture
on the Insulation Resistance
of Transformer Oil

Temperature = 55°C.



Relation between Megger Reading and Dielectric Value of Transformer Oil as Moisture is Added. Temperature = 55°C.



Curve sheet No. 7

Relation between Megger Reading and Dielectric Value of Transformer Oil as Moisture is Added. Temperature = 20°C.

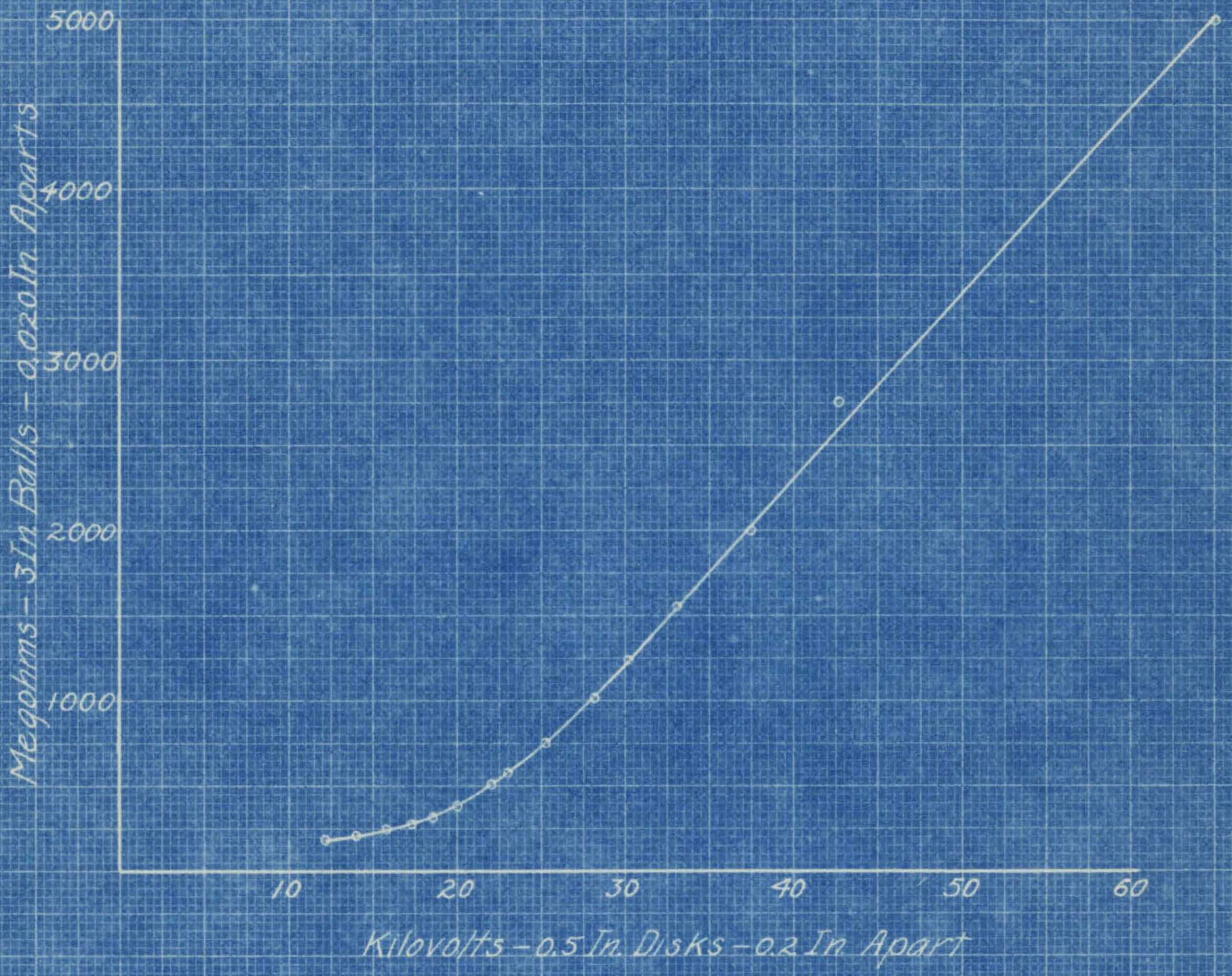
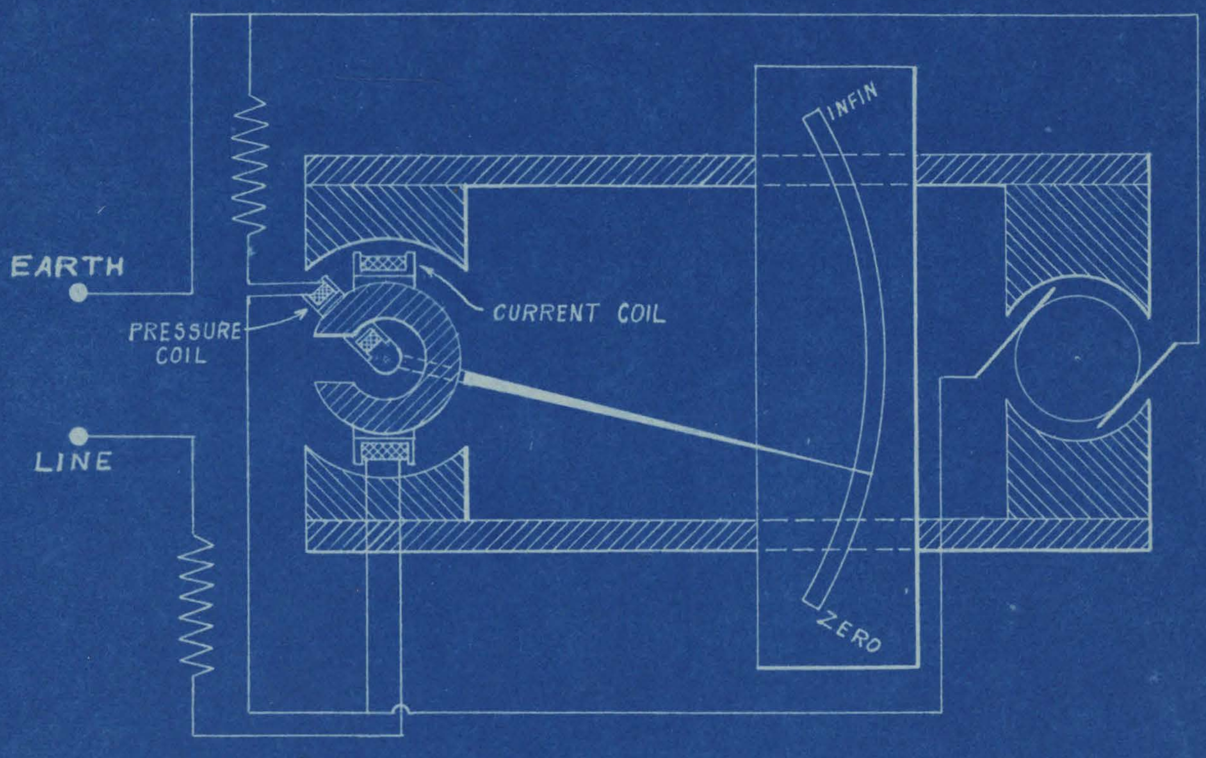
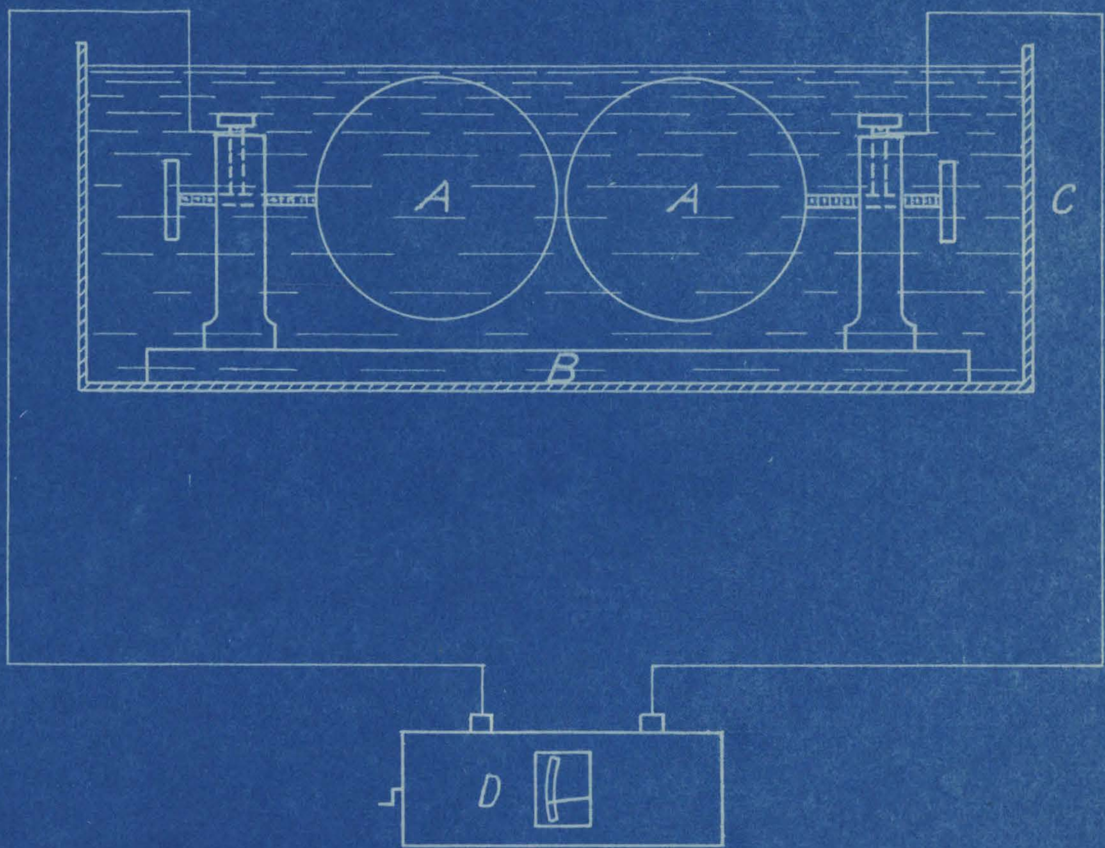


Diagram of Evershed Megger



Arrangement of Apparatus



AA- 3" Hollow copper spheres
B- Base of sphere gap — Composition board
C- Container for gap and oil
D- Megger