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# METHOD FOR IMPREGNATING CAPACITORS

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This invention relates to a process for impregnating with a liquid impregnant capacitors, and more particularly capacitors having metallized paper or paper-metal foil sections,

It is among the objects of the present invention to provide a method for satisfactorily impregnating metallized paper and paper-foil capacitors with liquid dielectrics, and more particularly, a method that will effect a substantial increase in the insulation resistance of the capacitor.

It is another object to provide a metallized paper or paper-foil capacitor that has a very high insulation resistance and high reliability though impregnated with a liquid dielectric.

In the past, it has not been believed practical to produce a metallized paper capacitor of high reliability, utilizing a liquid dielectric because of the apparent interference of the liquid dielectric with the so-called "self-clearing" ability of the metallized paper capacitor. When a local breakdown of the paper dielectric occurs because of the presence of an impurity, such as a minute particle of metal in the paper dielectric, the actual dielectric path between adjacent metal surfaces is shortened so that a greater discharge of energy tends to be concentrated in such path. This causes a burning out of the paper dielectric. However, if metallized paper is employed, the thin metal layer attached to the paper is vaporized, or otherwise disintegrated by the heat generated by the energy discharged, so that instead of two metal electrodes being separated by a hole created by the local destruction of the dielectric, there is simply a minute hole which passes completely through the electrodes also and therefore precludes short circuits, so that the capacitor is self-clearing.

However, if the paper separation of the metallized paper is impregnated with liquid dielectric, small conductive particles formed by the pyrolysis of the paper, and possibly also the liquid dielectric, will align themselves in the liquid medium and form a short circuit so that the capacitor is not self-clearing. The probability of such short circuits is increased by air in the interstices of the paper dielectric, which air may ionize and form a conductive path conducive to a short circuit. Accordingly, complete impregnation of the paper dielectric which minimizes the presence of such entrained air, tends to minimize development of short circuits.

It is accordingly another object of the present invention to provide a metallized paper capacitor which though utilizing a liquid impregnant, is substantially immune to the short circuiting difficulty ordinarily to be anticipated where such impregnant is utilized with that type of capacitor.

The process, according to the present invention, by which improved impregnation is effected, enables the use of a liquid dielectric in combination with metallized paper with a minimum of interference with the self-clearing ability of such capacitors. Such a process is especially useful when employed in combination with a liquid impregnant, such as polysiloxane or silicone oil, which does not decompose into conductive particles when localized pyrolysis occurs.

According to the invention, a capacitor that has been impregnated with liquid dielectric by conventional pressure variation treatment and sealed in its container, is thereupon further processed by heat treatment, more particularly, by gradually varying the temperature of the capacitor and its contained impregnant between predetermined maximum and minimum values. This cycle may be performed and repeated from 1 to 20 times or more. The heat treatment results in progressive improvement of impregnation, as evidenced by standard tests and performance characteristics. The improvement effected by the heat treatment of the invention may, depending upon the number of heating and cooling cycles employed, reach as high as 50 percent or more in the Factor of Merit (expressed as the product of capacitance and insulation resistance), as compared to the quality of the capacitors otherwise identically prepared but not subjected to such heat treatment.



While, in practice, the lower limit of temperatures may be about 25° C. and the upper limit about 65° C., it will be understood that these minimum and maximum values may be varied widely, provided of course these limits are compatible with the chemical and physical characteristics of the impregnant used. While such minima and maxima may be varied from cycle to cycle if desired, without departing from the present invention, it is ordinarily preferable to maintain a predetermined minimum and a predetermined maximum temperature throughout the successive cycles of heat treatment of the capacitor.

According to another feature of the invention, the temperature change between upper and lower limits, is gradual, the temperature rise and fall in each cycle taking ordinarily from 1 to 4 hours and the capacitors are maintained at the maximum temperature for from 1 to 4 hours, desirably 2 to 3 hours.

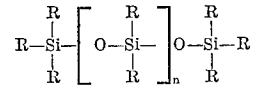
According to another feature of the invention, a time interval, ordinarily of several hours, is allowed to elapse between the end of the cooling step and the commencement of the re-heating step in the subsequent cycle, which contributes to uniformity of the product.

The metallized paper or paper-foil capacitors which are impregnated by the process of the present invention have sections which are generally composed of electrodes of thin metal, such as aluminum, zinc, barium or the like, separated by layers of dense kraft paper. The capacitor section may be formed from paper with the associated electrode of metal coated thereon, that is of metallized paper. Alternatively, the metal foil electrodes may be interleaved between layers of paper. In either case, the capacitor is made up of alternate layers of metal and paper, with the paper serving as dielectric intervening between the electrodes. The alternate layers of metal and paper may be wound on an arbor and the sections thus formed are placed in a suitable container which is conventionally a thin tube of metal, but which alternatively may be a hollow cylinder of treated ceramic or other liquid impermeable material. After the leads have been secured to the capacitor section, the capacitor undergoes a standard impregnation treatment. This involves immersing the capacitor in a bath of impregnant at elevated temperatures in an enclosed vessel. A substantial vacuum is then applied to the vessel in order to draw the impregnant into the capacitor section. The vacuum may be broken and re-applied a number of times. Vacuum treatment may be followed by a pressurizing treatment if desired. After the standard impregnation treatment, the capacitor sections are hermetically sealed.

According to the present invention, the impregnated capacitors are then subjected to an additional heat treating process which may be and conveniently is accomplished by varying the temperature of the ambient atmosphere.

The preferred impregnant, according to the present invention, is a silicone oil because of its low power factor, high insulation resistance and substantial invariance of the dielectric constant over a wide temperature range.

Silicone oils, chemically known as polysiloxanes, have the general formula:



where each R is some alkyl group, usually of from one to three carbon atoms.

In its broader aspects, the invention may be carried out by resorting to other liquid dielectric impregnants, such as hydrocarbons and halogenated hydrocarbons, an example of which is fluorochloroethylene. Although some of these materials do not possess the temperature stability and desirable electrical characteristics of silicone oils, they may be used in some applications in which economy is of primary importance and in which the application of the capacitor is such that substantial temperature change is not reasonably to be expected. A wide variety of such liquid impregnants may be employed in practicing the process of the present invention.

In one specific embodiment of the present invention, a capacitor section made up of enrolled layers of kraft paper metallized with a coating of aluminum of the thickness of 0.0002", is placed in a liquid- and vapor-impervious encasement tube. The capacitors are then vacuum impregnated through the open ends of the encasement tube with silicone oil under vacuum in the conventional manner at temperature of about 125° C. The silicone oil used in this embodiment and in other specific embodiments subsequently set forth is a polysiloxane, manufactured by Dow-Corning Company, of Midland, Michigan, and designated by them as DC–200. This silicone oil has a viscosity of 500 centistokes, a dielectric constant measured at 1000 cycles of 2.75, a surface tension of 21.1 dynes per centimeter, a specific gravity of 0.972 at 25° C. and a thermal coefficient of expansion of 9.0 x $10^{-4}$/° C.

A multiplicity of the capacitors thus impregnated were hermetically sealed while still hot and placed in an oven maintained at a constant temperature of about 25° C. The capacitors with their hot silicone oil filling are there allowed slowly to cool to approximately the temperature of the oven. Thereupon the temperature inside the oven is gradually raised, taking 2½ hours to reach about 65° C. This temperature of about 65° C. is maintained substantially constant for approximately 3 hours, after which period the atmosphere is allowed gradually to cool, taking 2½ hours to reach the original temperature of 25° C.

During the first heating step, the silicone oil impregnant expands so that its volume is from 6 percent to 10 percent greater than that which it occupied at 25° C., the original temperature prior to heating. The resulting expansive force, it is believed, tends to pump oil into the small spaces between the adjacent layers of the paper and metal and the even smaller interstices of the dense paper dielectric. The temperature of 25° C. is maintained for a predetermined period, in the particular embodiment described for about 8 hours before commencing the next cycle.

The cycle of heating and cooling as aforesaid is then repeated a number of times, thus repeating the pumping action. Each repetition of this cycle wets theretofore inaccessible spaces of the interstices within the capacitor section and leads to progressively more complete impregnation. It has been found that excellent improvement in the insulation resistance and reliabilty, heretofore unattained in a capacitor of this type may be obtained by twenty repetitions of the heating and cooling cycle just described.

The improvement in insulation resistance obtained by the heat treating process is illustrated by the data set forth in Table I below. A series of 15 capacitors having sections wound of kraft paper coated with aluminum, as aforesaid, was prepared and the capacitors impregnated with silicone oil in the conventional manner. The measurements hereinafter set forth were made on each of these capacitors. Thereupon the capacitors were subjected to the heat treatment of the invention, in which the heating and cooling cycle was repeated 20 times. Table I, below, shows the comparison between the capacitors before and after heat treatment. The factor measured was a Factor of Merit obtained by multiplying the capacitance and insulation resistance measured. In each case, the Factor of Merit increased substantially as a result of the heat treatment. An average increase in the Factor of Merit of almost 50 percent was obtained by the invention.



*Table I*

| Unit No. | Untreated (Factor of Merit) (Megohm-Microfarads) | Treated (Factor of Merit) (Megohm-Microfarads) |
|---|---|---|
| 1 | 9,621 | 10,498 |
| 2 | 8,472 | 10,532 |
| 3 | 7,492 | 11,498 |
| 4 | 8,700 | 12,253 |
| 5 | 9,304 | 16,868 |
| 6 | 4,687 | 13,855 |
| 7 | 7,737 | 13,392 |
| 8 | 8,890 | 11,388 |
| 9 | 10,567 | 17,830 |
| 10 | 8,916 | 16,140 |
| 11 | 10,933 | 11,783 |
| 12 | 9,679 | 11,182 |
| 13 | 9,269 | 11,654 |
| 14 | 8,287 | 11,960 |
| 15 | 10,212 | 13,314 |

The heat treating procedure of the present invention was found highly beneficial, not only when the heating and cooling cycle was carried out twenty times as in the examples given above, but also in cases where fewer cycles of heating and cooling were employed. Naturally, when the same temperature differential is used and fewer cycles employed the improvement is somewhat smaller, but has been found, nevertheless, to be quite significant.

A plurality of metallized paper capacitors, impregnated with the silicone oil whose properties have been set forth above were tested to determine their factor of merit in terms of megohm-microfarads. The same units were then subjected to the same heat treatment previously described except that the heating and cooling cycle was repeated only four times. Other substantially identical capacitors were treated with 10 cycles of heating and cooling. In the first set of capacitors, based on 25 units tested, an average Factor of Merit prior to treatment of 11,800 megohm-microfarads was obtained. After treatment for a period of two days, with four cycles of heating and cooling, an improvement in the factor of merit to 15,100 megohm-microfarads, i.e., an increase of about 20 percent was obtained.

After five days of treatment or 10 heating and cooling cycles, the factor of merit was increased to 16,500 megohm-microfarads, or an increase of about 40 percent.

Because of the higher insulation resistance obtained by the heat treatment of the present invention, capacitors made in this way have been found to fail much less frequently when subjected to so-called "life tests." In life testing of the capacitors, the units are subjected to a voltage in substantial excess of their rated voltage and maintained at an elevated temperature for an extended period. The insulation resistance of these capacitors is measured continuously and a failure is considered to have occurred when the insulation resistance dropped below a predetermined value.

A group of 24 paper-aluminum foil capacitors were impregnated with silicone oil under a vacuum in conventional manner and then hermetically sealed. Twelve of these units were then heat treated for 10 days under the conditions set forth above and the entire group of capacitors was then put on life test. This was done by subjecting the capacitors which had a rated voltage of 200 volts to a direct current of 280 volts, or 40 percent in excess of their rated voltage. The tests were carried out

in an atmosphere maintained at 125° C. Of the untreated capacitors, one failure occurred after 210 hours of testing, two occurred after 401 hours. After 500 hours, it was found that none of the treated capacitors had failed. Such superior performance is deemed to be directly attributable to the heat treating process of the present invention, since the capacitors tested were otherwise identical in all respects.

It will be understood, of course, that the process of the present invention, while it has been illustrated by the use of certain specific temperatures and times and lengths of conditioning treatment and particular impregnant, is not limited to such specific embodiments, but embraces various equivalents suggested from reading of the foregoing specification. Thus the invention may be practiced using different impregnants or larger or smaller differential between the maximum and minimum temperatures, as well as different periods of heating and cooling and different numbers of repetitions of the heating and cooling cycle.

Having thus described our invention, what we claim as new and desire to secure by Letters Patent of the United States is:

1. In the method of impregnating with liquid impregnant, a capacitor section of the type comprising electrodes and intervening spacers having interstices therein, by drawing the impregnant under pressure variation and heat between the electrodes and into such interstices and thereupon sealing the capacitor section in a container; the further step of subjecting the thus impregnated and sealed capacitor to a series of heat treating cycles, each of which consists of gradually varying the temperature of the capactior and its dielectric between lower and upper limits, wherein the upper limit of temperatures and the lower limit of temperatures of each cycle are each maintained for a substantial period of time.

2. The method according to claim 1 in which the lower limit of temperature variation of each cycle, as well as the upper limit of temperature variation of each cycle, is of predetermined value.

3. The method according to claim 1 in which the upper limit of temperature of each cycle is maintained for a period of time in the order of at least one hour and the lower limit of temperature of each cycle is maintained for a period of time of at least one hour.

4. The method according to claim 1 wherein the liquid impregnant is polysiloxane.

5. The method according to claim 1, wherein the heat



treatment is executed in a plurality of cycles and wherein the upper limit of temperatures in each cycle is maintained for a period of time in the order of at least one hour and wherein the lower limit of temperature after each cycle is maintained for a period of at least one hour before the rise of temperature at the commencement of the succeeding cycle.

6. The method according to claim 1, wherein the heat treatment is executed in a plurality of cycles and wherein the liquid impregnant is a polysiloxane.

7. The method according to claim 1, wherein the lower temperature limit of each cycle is about 25° C. and the upper temperature limit of each cycle is about 65° C.

8. In the method of impregnating a capacitor section of the type comprising aluminum electrodes with intervening paper spacers having interstices therein, by drawing liquid dielectric under vacuum and heat between the electrodes and into such interstices and thereupon sealing the capacitor section in a substantially liquid-tight container; the use of polysiloxane as the liquid dielectric, the further step which consists in subjecting the thus impregnated and sealed capacitor to heat treatment by placing said impregnated capacitor in an ambient atmosphere maintained at about 25° C., gradually raising the temperature of said ambient atmosphere to about 65° C. for about 2½ hours, thereafter maintaining the temperature of said ambient atmosphere at about 65° C. for about three hours, gradually lowering the temperature of said ambient atmosphere to about 25° C. in a period of about 2½ hours, maintaining the temperature of said ambient atmosphere at about 25° C. for a period of about 8 hours and thereupon repeating a plurality of the cycles of heating and cooling of the ambient atmosphere as aforesaid.

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