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SELF-EXTINGUISHMENT OF CORONA DISCHARGE
IN ELECTRICAL APPARATUS
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Fig. 1.

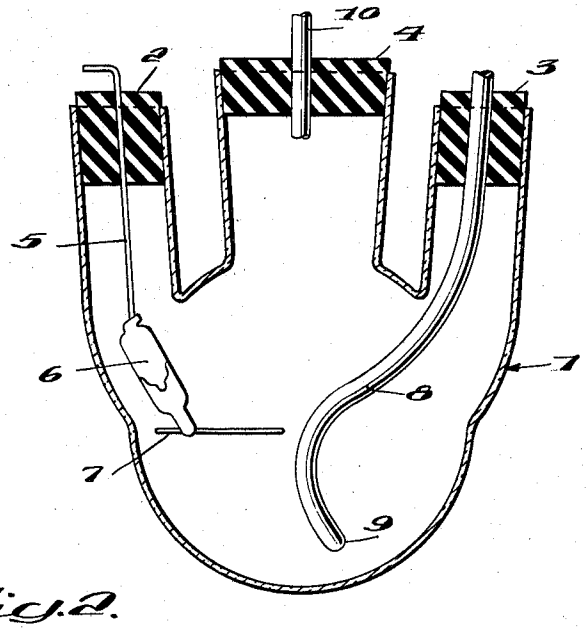
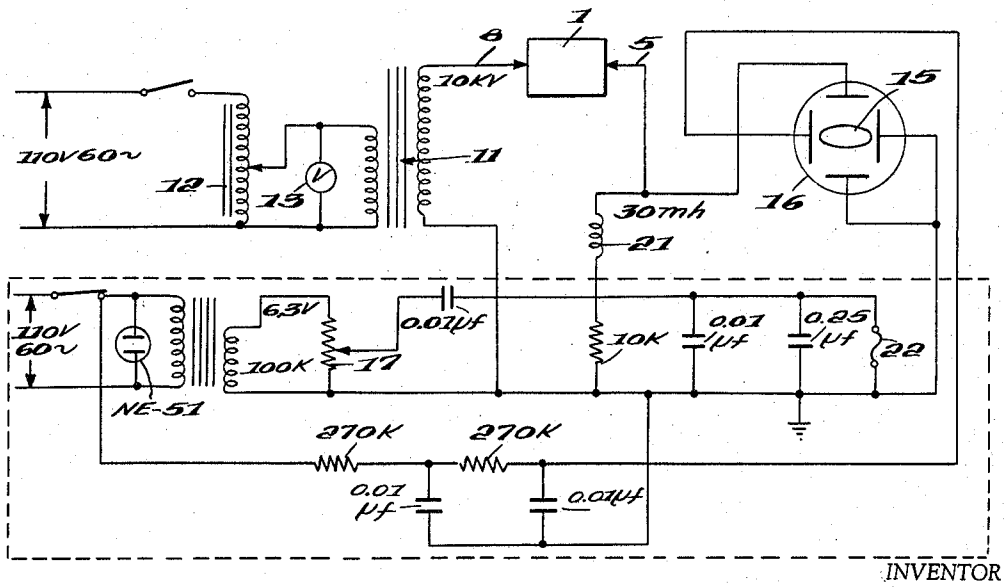


Fig. 2.



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SELF-EXTINGUISHMENT OF CORONA DISCHARGE IN ELECTRICAL APPARATUS

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This invention relates to electrical devices, and more particularly to those employing gaseous dielectrics.

It is known that, in electrical devices such as those in which electrical conductors of different potentials are arranged near each other, various types of discharges between the conductors are possible and all too frequently occur, such as the spark-over or arcing, glow discharge, point discharge, silent electrical discharge, and corona (or crown discharge). Often fluids, both gases and liquids, are used to prevent the arcing or spark-over discharge. Where gases are used as the dielectric, other types of discharges are quite frequent. The glow discharge, however, which takes place only at greatly reduced pressures, does not ordinarily occur in the general types of electrical apparatus.

The present invention is more particularly directed to a method for reducing the corona discharge which occurs when highly stressed, non-uniform electrical fields exist over restricted areas. In the present invention, the term "corona" discharge will be used to include the so-called point discharge and silent electrical discharge which in many cases are referred to as "corona."

In this type of discharge, ordinarily the current flow is self-limiting although typical examples of a corona discharge occur where voids exist in solid insulation or between conductors which, due to imperfections, do not have a uniform surface. Unlike the glow discharge, the corona discharge occurs at about 0.1 atmosphere pressure and above. While various methods have heretofore been employed in an attempt to control corona discharge, none of them has been completely satisfactory. Unlike arcing or spark-over which causes immediate damage to electrical equipment, the corona discharge gives slow but cumulative effects which in many cases are serious since they cause deterioration of solid, liquid and gaseous insulating materials.

It is an object of the present invention to provide electrical apparatus in which the corona discharge will be self-extinguishing, by employing as the gaseous dielectric, or as an addition to the gaseous dielectric, a material which under the influence of the corona discharge will produce a non-conducting or semi-conducting deposit on the conductor at the point or over the area of corona discharge.

It has now been found that corona discharge in electrical apparatus, in which gases are used as the dielectric material alone or in conjunction with other dielectric material, can be effectively reduced by employing a gaseous dielectric which, under the influence of the corona, produces a non-conducting or semi-conducting solid on the point or over the area at which the corona discharge occurs. The gaseous dielectrics with which the present invention is concerned are those which normally prevent the arcing (spark-over) between conductors under normal operating conditions. The gaseous dielectrics generally employed for this purpose have been found to be ineffective against corona discharge in the apparatus in which they are employed, such as in transformers, shielded high voltage electric cables, capacitors, condensers or similar types of apparatus. In all such devices conductors under different electric potentials exist relatively close to each other, and in such devices corona can and often does

occur particularly where high voltages exist or where such occur even momentarily such as in the starting of electrical motors or where overloads occur in the conductors.

Corona occurs where a field of high electrical stress exists, such as where voids exist in solid insulation on wires or where the normal smooth surface of the conductor is marred by points or burrs such as those which occur on wire due to the imperfections in the wire-drawing process.

Corona often can be detected visually, particularly in total darkness, where it appears as a faint glow. Other forms of the same phenomena may not be apparent visually. A more convenient and much more sensitive method for detecting corona discharge in any form is by the use of a cathode ray oscilloscope, such as described hereinafter.

As previously stated, the present invention contemplates adding to a gaseous dielectric a gaseous material or a low boiling liquid which under conditions of operation of the apparatus has a substantial vapor pressure and which under the influence of the corona discharge itself forms a non-conducting or semi-conducting solid material. The compounds used in the present invention are inorganic compounds which either by themselves or in combination with the gaseous dielectric with which they are used under the influence of an ionizing electrical discharge, form deposits at the point where the corona discharge occurs. Since it has been found that these deposits are either non-conductors or semi-conductors, the extinguishment of the corona is believed to be due to the spreading of the stressed electrical field over a larger area and thus diminishing the stress, or by more completely insulating the area where the corona orginally takes place.

The corona extinguishing substances of the present invention may also be used as the gaseous dielectric itself if it has the necessary dielectric and other properties. In general, however, they will be used as additives to gaseous dielectrics which do not themselves cause self-extinguishment of corona. It is of course necessary to have a sufficient amount of the corona extinguishing gas present to produce a deposit over the corona-producing area when the corona discharge takes place. The minimum partial pressure of the corona-suppressing substance should be at least about 50 mm. of mercury. Of course no upper limit is set since the corona-suppressing substance may be the dielectric material itself, in which case the total pressure would be that of the corona-suppressing substance.

It is of course understood that there is a corona starting voltage for a given system depending on both the dielectrics and the conductors and the configuration of the conductors. When the starting voltage is exceeded, corona occurs. It is frequently possible to extinguish corona without changing the voltage, such as by increasing the pressure of the dielectric gas or by replacing part of the dielectric gas with a material having better dielectric properties, but these methods give only temporary relief without correcting the factors which tend to produce the corona. "Self-extinguishment of corona" is used herein to mean that, after the corona starting voltage has been exceeded and corona is occurring, the corona will extinguish itself without any other change being made. This has the advantage of being automatic in nature, whereby the corona is extinguished even without knowledge that the corona discharge is taking place.

In general, the compounds which according to the present invention may be used for self-extinguishment of corona will be those inorganic compounds which in the presence of an ionizing electrical discharge produce a solid deposit which is a non-conductor or a semi-

conductor of electricity. Illustrative of the compounds found to be effective in the self-extinguishment of corona are: phosphorus pentafluoride, bispentafluorosulfur oxide [$(SF_5)_2O$], ammonia, hydrogen sulfide, sulfur chloride pentafluoride ($SClF_5$), sulfur tetrafluoride, hydrogen chloride, carbon monoxide, hydrogen bromide and hydrogen iodide.

The above-mentioned compounds which may be used for self-extinguishment of corona will generally be added in relatively small amounts to the usually gaseous dielectric materials, although, as stated above, they can be used alone where they exhibit the otherwise required dielectric properties. In addition to the particular dielectric materials disclosed in the specific examples, the following further exemplify the gaseous dielectrics with which the compounds of the present invention may be employed: 2-chloroheptafluoropropane, decafluorobutane, chloropentafluoroethane, octafluoropropane, hexafluoroethane, 1,2-dichlorotetrafluoroethane, 1,1,2-trichlorotrifluoroethane, perfluoro-(2-n-butyltetrahydrofuran), perfluorotrimethylamine, chlorotrifluoromethane, carbon tetrafluoride, nitrogen, helium, hydrogen, carbon dioxide and octafluorocyclobutane. It is of course understood that the corona-extinguishing compounds of the present application may be used with any gaseous dielectric since quite obviously under the conditions employed in their use as dielectrics there will normally be no reaction between the corona extinguishing compounds and the dielectric materials.

The following examples are based on tests of the corona extinguishing compounds which have been carried out in an apparatus more particularly illustrated in the attached drawing which forms a part of the present application. In this drawing, FIGURE 1 shows the test apparatus, while FIGURE 2 is a wiring diagram for a cathode ray oscilloscope circuit used in detecting corona discharge even where it was not apparent visually.

The apparatus of FIGURE 1 of the drawing comprises a common three-necked, round-bottomed flask **1**, which can conveniently be of 500 cc. capacity. Rubber stoppers (polychloroprene) **2**, **3** and **4** were used. Through stopper **2** there is sealed a copper wire **5** to which is attached a small alligator clamp **6** in which a steel needle **7** is held. Through stopper **3** is sealed a ¼" outside diameter copper tube **8**, the end **9** of which is crimped closed and soldered. The end of needle **7** is adjusted to about ¼" from the nearest point on the tube **8**. Through the center stopper **4** an inlet copper tube **10** is provided to permit the removal and introduction of various gaseous materials to the system. The leads of the secondary winding of a 10,000 volt transformer **11**, see FIGURE 2 (secondary rated at 23 milliamperes), are attached through a circuit as illustrated in FIGURE 2 of the drawing to electrodes **5** and **8**. The primary windings of the transformer are attached to a source of electric power through a variable transformer **12** so that there can be supplied to the primary windings a voltage ranging from 0 to 130 volts of alternating current.

Observations were sometimes made visually by connecting the 10,000-volt transformer, **11**, directly to the electrodes **5** and **8**, leaving out the remainder of the circuit of FIGURE 2.

The tests were carried out at approximately room temperature (about 77° F.). The flask was evacuated to approximately 0.05 mm. Hg pressure. Where the corona self-suppressing agent to be used with the gaseous dielectric was a gas at room temperature and atmospheric pressure or a relatively volatile liquid, the gas of lower molecular weight was added first, then the second gas of higher molecular weight was introduced. The partial pressures of each material of course determined the mole ratio of the materials that were used in the flask. Then, a small area of the side of the flask was heated to cause convection in the cell to produce more rapid mixing of the gases. This was repeated several times to provide thorough mixing. Where vapors of liquids are used, the liquid itself may be introduced into the flask to provide the desired vapor pressure. For best results, the rubber stoppers in the flask were changed frequently to prevent absorbed materials from contaminating materials in subsequent tests.

While the corona in many cases could be observed visually when the test was run in a darkened room, the use of a cathode ray oscilloscope gave much more accurate determination of the presence or absence of corona discharge.

In the following examples the voltage applied as read on the voltmeter **13** was generally increased until corona was observed either visually or by the oscilloscope. In the examples the voltage given is that actually used on the secondary winding of the transformer calculated from the voltmeter reading of the voltage of the primary winding as shown on the drawing, using a factor of 86.8. If the corona extinguished itself, the effect of increased voltage was determined. It is to be understood that there is a limiting voltage that can be applied to any system, above which arcing takes places. The voltage which can be used is determined by the materials in the system and their pressures. If the voltage is maintained near the spark-over or arcing voltage, permanent suppression of corona will usually not be obtainable, so that the tests are run at voltages below that which results in arcing.

FIGURE 2 of the drawing illustrates the external circuit employed with the apparatus of FIGURE 1 where a cathode ray oscilloscope **16** is used. Since this oscilloscope is a standard commodity of commerce, the internal circuits are not shown. The circuit shown inside the dotted-line rectangle produces an elliptical Lissajous figure as at **15** on the oscilloscope **16**, with the major axis substantially horizontal. The vertical dimension of the Lissajous figure was adjusted by means of a 100K ohm variable resistor **17**. When corona occurred, it appeared on the oscilloscope as vertical lines superposed on the Lissajous figure **15**. The electrodes from the test cell or flask **1** in FIGURE 1, which in FIGURE 2 is indicated diagrammatically at **1**, were arranged so that the needle side or copper wire **5** of the test cell circuit was connected directly to the oscilloscope **16**, and a 30 millihenry high frequency choke **21** was inserted between the needle circuit and the circuit which generated the Lissajous figure **15**. A protector **22** of a special type consisting of a piece of silicone-treated paper between a plate and a spring electrode was provided to protect the oscilloscope in case of flash-over between the needle **7** and tube **8** in FIGURE 1.

The following specific examples are given to more fully illustrate the invention. In the examples, the tests were carried out at approximately one atmosphere pressure. At this pressure the corona was observed conveniently and readily. Too low a pressure is avoided, since it would give the glow phenomena previously referred to.

Example I

The test cell described above was evacuated to less than 0.05 mm. Hg pressure. Then a mixture of sulfur hexafluoride and 15 mole percent phosphorus pentafluoride was admitted to produce a total pressure of one atmosphere. Sixty cycle alternating current was applied and the voltage gradually raised until corona occurred. The cell was then observed to determine whether corona was extinguished. The test was repeated using $(SF_5)_2O$, ammonia, hydrogen sulfide, sulfur chloropentafluoride, sulfur tetrafluoride, hydrogen chloride, carbon monoxide, hydrogen bromide and hydrogen iodide. The results are shown below.

SF_6+15 MOLE PERCENT ADDITIVE AT 1 ATM.

Additive:	Results
PF_5	Extinguishes corona slowly.
$(SF_5)_2O$	Do.
NH_3	Do.

Additive:	Results
H_2S	Extinguishes corona slowly.
$SClF_5$	Do.
SF_4	Do.
HCl	Extinguishes corona very slowly.
CO	Extinguishes corona slowly.

When hydrogen chloride is replaced by hydrogen bromide or hydrogen iodide in the above test, similar results are obtained.

The deposits formed on the needles using PF_5 and NH_3 were nonconductors while those using $(SF_5)_2O$, H_2S, SF_4, CO, HCl, HBr, HI and $SClF_5$ were semiconductors. This was shown in the following test.

One lead of a direct current resistance measuring unit was connected to an unused steel needle and the other to a pool of mercury via an immersed electrode. The ohmmeter indicated infinite resistance as the needle was lowered toward the mercury pool until contact was made when zero resistance was indicated. Needles used in the above tests were carried through the same test. As the tip of the needles came into contact with the mercury, a zero resistance was not obtained. Either infinite resistance or a rather high resistance reading was obtained. The high but not infinite resistance indicated a semiconductor.

The semiconductor nature of the deposits was confirmed by putting a 10,000 ohm resistor in series with the needle, connecting an oscilloscope across the resistor and applying a fraction of a volt to 6 volts—60 cycle A.C. to the circuit. The amplitude of the cycles recorded on the oscilloscope increased or decreased as the needle was immersed in the mercury, again indicating the semiconductor nature of the deposits.

Example II

Using the same apparatus as in Example I, mixtures containing sulfur hexafluoride and 15 mole percent of the following were tested at one atmosphere total pressure: sulfuryl fluoride, carbon dioxide, helium, argon, nitrogen, nitric oxide, nitrogen trifluoride, oxygen and hydrogen.

None of these materials were found to cause self-extinguishment of corona.

Example III

Using the apparatus of Example I, the mixtures shown below were tested at one atmosphere total pressure.

Dielectric Gas	Additive	Partial Pressure, mm. Hg	Results
SF_6	NH_3	50	Corona extinguishes.
SF_6	NH_3	30	Corona does not extinguish.
Perfluorocyclobutane	NH_3	84	Corona extinguishes
N_2	NH_3	84	Do.

A partial pressure of 84 mm. of mercury corresponds to 15 mole percent.

The corona-suppressing agents of the present invention may be used in all types of electrical apparatus where corona discharge takes place, such as in ordinary electrical transformers, vapor-cooled transformers such as disclosed in U.S. Patents 2,777,009 and 2,886,625, communication cables such as described in U.S. Patent 2,221,670, power cables where gaseous dielectrics are employed, capacitors, electronic equipment, or wherever it is desired to prevent permanent damage to the insulation by corona discharge.

What is claimed is:

1. A gas-tight electrical apparatus containing at least one electrical conductor from which corona-type discharge may occur, a gaseous dielectric surrounding said conductor; said gaseous dielectric comprising as a corona self-suppressing agent a gaseous inorganic compound selected from the group consisting of phosphorus pentafluoride, bis-pentafluorosulfur oxide, ammonia, hydrogen sulfide, sulfur chloro-pentafluoride, hydrogen chloride, hydrogen bromide, hydrogen iodide, and carbon monoxide, said corona self-suppressing agent having a partial pressure of at least 50 mm. of mercury in said gaseous dielectric, and said corona self-suppressing agent being capable of producing a solid deposit of a material of a class consisting of non-conductors and semi-conductors of electricity over said electrical conductor when in the presence of corona discharge, whereby the corona discharge is effectively extinguished.

2. A gas-tight electrical apparatus as in claim **1** wherein the corona self-suppressing agent is phosphorus pentafluoride.

3. A gas-tight electrical apparatus as in claim **1** wherein corona self-suppressing agent is bispentafluorosulfur oxide.

4. A gas-tight electrical apparatus as in claim **1** wherein corona self-suppressing agent is ammonia.

5. A gas-tight electrical apparatus as in claim **1** wherein corona self-suppressing agent is hydrogen sulfide.

6. A gas-tight electrical apparatus as in claim **1** wherein corona self-suppressing agent is sulfur chloropentafluoride.

7. A gas-tight electrical apparatus as in claim **1** wherein corona self-suppressing agent is hydrogen chloride.

8. A gas-tight electrical apparatus as in claim **1** wherein corona self-suppressing agent is hydrogen bromide.

9. A gas-tight electrical apparatus as in claim **1** wherein corona self-suppressing agent is hydrogen iodide.

10. A gas-tight electrical apparatus as in claim **1** wherein corona self-suppressing agent is carbon monoxide.

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