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ELECTRICAL APPARATUS

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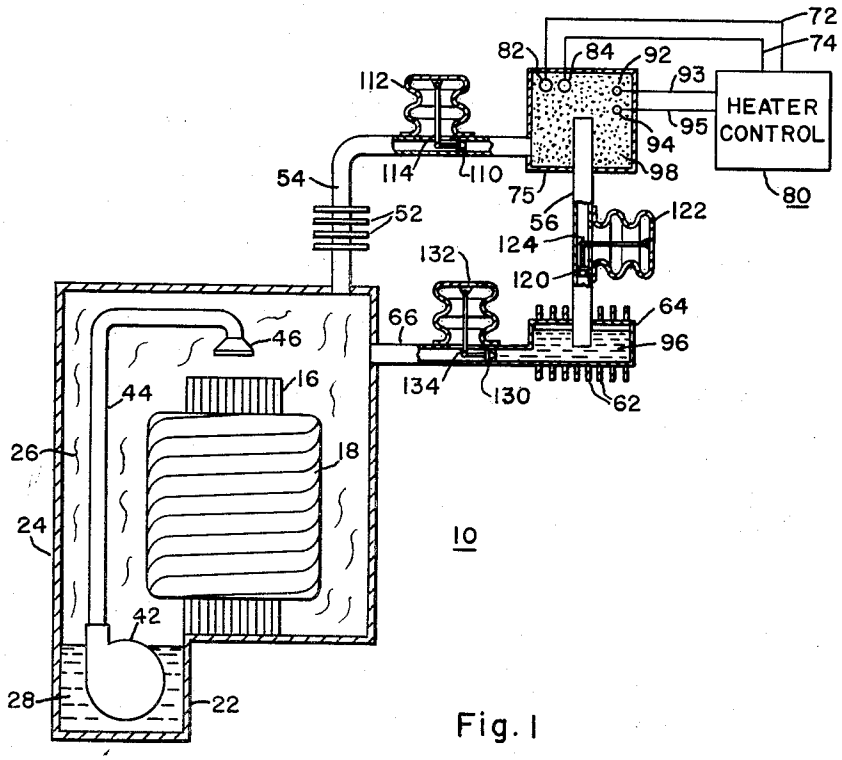



Fig. 1

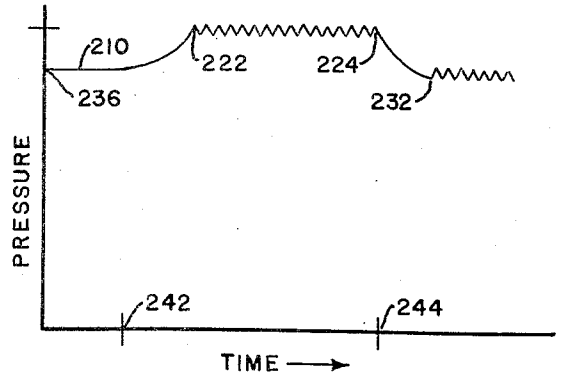



Fig. 2

WITNESSES

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3,023,263

# ELECTRICAL APPARATUS

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This invention relates to electrical apparatus and more particularly to apparatus utilizing vaporization of a liquid dielectric to dissipate the heat developed during operation of the apparatus and utilizing the vapors of the dielectric liquid as an insulating medium.

In U.S. Patent No. 2,561,738, filed November 4, 1949, by C. F. Hill and assigned to the same assignee as the present application, there is disclosed an enclosed electrical apparatus employing a relatively small amount of fluorinated organic liquid coolant which is sprayed or applied over the electrical windings or conductors of the electrical apparatus to cool them by evaporation of the liquid coolant, the evolved vapors constituting a part of an electrically insulating gas mixture. Such apparatus is efficient in operation but has the disadvantage that the pressure of the insulating gas mixture developed within the casing varies greatly during the operation of the apparatus and the casing of the apparatus therefor must be constructed to withstand the maximum pressure which will result during the operation of said apparatus. In order to limit excessive pressures within the casing of such apparatus, it is desirable to provide means with such apparatus for maintaining the pressure of the insulating gas within the casing at substantially a predetermined value or within substantially a predetermined range of operating values whereby excessive pressures are prevented and the dielectric strength of the insulating gas is maintained above substantially a minimum value. In copending application Serial No. 744,182, filed June 24, 1958, by A. J. Maslin et al. and assigned to the same assignee as the present application (not Patent 2,961,476 granted November 22, 1960), there is diclosed means for maintaining the pressure in the casing in electrical apparatus of the type described at substantially a predetermined value which includes the use of a flexible container. It is also desirable to provide electrical apparatus of the type described which has all of the advantages of the electrical apparatus disclosed in the copending application just mentioned and which has certain additional advantages, such as not requiring the use of a flexible container.

It is an object of this invention to provide a new and improved electrical apparatus including elements sealed in an enclosing casing, a vaporizable liquid fluorinated compound for cooling and insulating such elements, a substantially non-condensable gas for insulating said elements until said liquid compound vaporizes, and means for segregating the vapors of said liquid and said non-condensable gas after said apparatus heats up.

Another object of this invention is to provide a sealed electrical apparatus including an enclosing casing, an insulating gas which comprises a mixture of the vapors of a liquid fluorinated compound, which also serves in the cooling of the apparatus, and a substantially non-condensable gas, which is segregated from the vapors of the compound as the temperature of the apparatus increases, and means for maintaining the pressure of the insulating gas in said casing within substantially predetermined limits.

Other objects of the invention will, in part, be obvious and will, in part, appear hereinafter.



For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing, in which:

FIGURE 1 is a diagrammatic view of a transformer constructed in accordance with this invention; and

FIG. 2 is a graph illustrating the variation of the pressure of the insulating gas within the casing of an electrical apparatus as disclosed during its operation.

Similarly to the electrical apparatus disclosed in the Hill patent previously mentioned, an enclosed electrical apparatus is provided that combines the advantages of the liquid dielectric filled type of apparatus in many respects and also has the advantages of the gas filled types of electrical equipment with few or none of the disadvantages of either type of apparatus, and with several unique advantages of its own. Specifically, the operating electrical elements or windings of the apparatus are cooled by flowing, spraying or otherwise distributing over the surface to be cooled in layers, streams or films of certain liquid fluorinated organic compounds having a boiling point of between 50° C. and 225° C. at atmospheric pressure. The fluorinated organic compound or a mixture of two or more compounds cools the electrical elements mainly by its evaporation. The fluorinated organic compound vapors so evolved flow to the enclosing casing in which the elements are disposed and condense on contact with a relatively cool wall of the casing or they may be condensed in a radiator or by other suitable cooling means. The condensed portion of the liquid compound and any portion of the liquid compound that did not evaporate when sprayed or flowed over the electrical windings are collected and reflowed or resprayed. A relatively small amount of liquid fluorinated organic compound has been found to be sufficient for effective cooling of the particular electrical apparatus.

In order to provide the necessary insulation during the operation of the electrical apparatus, an insulating gas is provided in the casing of the electrical apparatus which is a mixture of a relatively inert gas, which is substantially non-condensable over the normal range of operating temperatures and pressures of the associated apparatus, and the vapors of the fluorinated organic compound. The non-condensable gas is necessary to ensure adequate initial insulation and to enable operation with relatively slight variations in the internal gas pressure in the casing. When the apparatus is cold or inoperative, the non-condensable gas constitutes the predominant volumetric portion of the insulating gas, and the vapors of the fluorinated compound constitute the minor component. When the apparatus is operating, the temperature will increase with the applied load and the composition of the atmosphere immediately surrounding the windings will comprise a greater proportion of the vapors of the fluorinated compound. Mixtures of a non-condensable gas, such as sulfur hexafluoride or nitrogen, and the vapors of the fluorinated compounds, however, are not efficient in conveying heat from the windings to the casing walls or radiator of an electrical apparatus since the non-condensable gas impedes the flow of the evolved vapors to the radiator or casing walls and impairs its condensation. In order, therefore, to obtain the most efficient dissipation of the heat developed in the operating elements of an enclosed apparatus, the non-condensable gas must be segregated from the vapors of the fluorinated compound during operation so that substantially only the vapors of the fluorinated compound are present in the portion of the casing adjacent to the operating elements after the temperature of the operating elements has increased to substantially a predetermined value. This is accom-

plished by providing the casing of the apparatus with a connecting auxiliary housing in which is disposed a quantity of a gas adsorbing material, more specifically a quantity of gas adsorbing solid, which may be finely divided or molded into a porous block. As the apparatus heats up during operation and the pressure of the insulating gas in the casing tends to increase because of the evolved vapors of the fluorinated compound, the gas adsorbing material gradually adsorbs the non-condensable gas to thereby limit the pressure of the insulating gas in the casing to substantially a predetermined value. The auxiliary housing containing the gas adsorbing material is connected at the upper end of the casing since the vapors of the fluorinated compound are normally denser than any non-condensable gas found to be practical in the apparatus and the segregation of the gases in the above manner utilizes this difference in density. The vapors also tend to be segregated from the non-condensable gas because of the condensation of the vapors.

In order to maintain the pressure of the insulating gas in the casing of the electrical apparatus and the corresponding dielectric strength of said insulating gas above substantially predetermined minimum values, the electrical apparatus is also provided with means for desorbing the non-condensable gas from the associated gas adsorbing means and returning it to the casing of said apparatus whenever the pressure of the insulating gas inside the casing decreases to substantially a predetermined value after the apparatus heats up during operation, and then subsequently cools to thereby condense the evolved vapors of the fluorinated compound and decrease the corresponding pressure of the insulating gas in the casing.

Different vaporizable liquid coolants are known to those skilled in the art and can be employed in practicing this invention. In practice, it is generally preferred to utilize the vaporizable liquid coolants disclosed in the Hill Patent 2,561,738 and in the copending application previously mentioned.

As disclosed in the Hill patent, the vaporizable liquid coolant may comprise the liquid fluorinated organic compounds selected from the group consisting of hydrocarbons, hydrocarbon ethers and tertiary hydrocarbon amines in which at least half the hydrogen atoms have been substituted by at least one halogen selected from the group consisting of chlorine and fluorine, and of which at least half of the halogen is fluorine. The hydrocarbons and the hydrocarbon groups attached to oxygen or nitrogen atoms may be aliphatic, aromatic, cycloaliphatic and alkaryl. Liquid perfluorocarbons, perfluorocarbon ethers and perfluorocarbon tertiary amines boiling between 50° C. and 225° C. have outstanding properties. Perhalocarbon compounds composed of only carbon and a halogen selected from at least one of the group consisting of chlorine and fluorine, of which fluorine comprises at least half the halogen atoms are excellent liquid coolants for the purpose of this invention.

The vapors of the fluorinated organic compound referred to hereinbefore have outstanding electrical insulating properties. They are superior to practically all other gases in such electrical insulating characteristics as breakdown strength, dielectric strength, power factor and resistance to formation of corona under similar conditions of temperature and pressure. These compounds are outstanding in their stability to chemical and thermal breakdown, being surpassed only by the permanent gases. The fluorinated compounds in the liquid state exert negligible, if any, solvent or deteriorating action on ordinary insulating materials and varnishes employed in the preparation of conventional electrical elements such as windings, cores and coils.

As examples of specific fluorinated organic compounds which may be utilized in practicing this invention either alone or in mixtures, reference may be had to the following list of fluorinated organic compounds:

| | Boiling point, °C. |
|---|---|
| Perfluorophenanthrane | 205 |
| Perfluorodibutyl ether | 100 |
| Perfluorotriethyl amine | 71 |
| Perfluorotributyl amine | 178 |
| Perfluorodimethylcyclohexane | 101 |
| Perfluoromethylcyclohexane | 76 |
| Perfluoro-n-heptane | 82 |
| Perfluorotoluene | 102 |
| Perfluorocyclic ether ($C_8F_{16}O$) | 101 |
| Perfluorocyclic ether ($C_6F_{12}O$) | 56 |
| Monochlorotetrafluoro-(trifluoromethyl) benzene | 137 |
| Dichlorotrifluoro-(trifluoromethyl) benzene | 170 |
| Trichlorodifluoro-(trifluoromethyl) benzene | 207 |
| Monochloropentadecafluoroheptane | 96 |
| 2-chloro-1,4-bis (trifluoromethyl) benzene | 148 |
| 2-chlorotrifluoromethylbenzene | 150 |
| Perfluorodiethylcyclohexane | 148 |
| Perfluoroethylcyclohexane | 101 |
| Perfluoropropylcyclohexane | 123 |
| Chlorononafluorobis(trifluoromethyl) cyclohexane | 129 |
| Perfluoronaphthalane | 140 |
| Perfluoro-1-methylnaphthalane | 161 |
| Perfluorodimethylnaphthalanes | 177 to 179 |
| Perfluoroindane | 116 to 117 |
| Perfluorofluorane | 190 |
| Perfluorobicyclo-(2.2.1) heptane (746 mm.) | 70 |

The amines and ethers may have dissimilar halogen substituted hydrocarbon groups present as, for example, 2,2-dichloro-1,1,1,-trifluoroethyl-perfluorobutyl ether and perfluorodibutylethyl amine. The freezing points of the above-listed liquid compounds are below 0° C., many being below —50° C., so that they can be safely employed, individually or in mixtures, under nearly all ambient conditions to be expected in service.

Examples of preferred suitable fluorinated compounds are the perfluorocyclic ethers, such as the compound having the formula $C_8F_{16}O$, although it will be understood that other fluorinated compounds as defined herein may be substituted in whole or in part therefor. The physical properties of the perfluorocyclic ether ($C_8F_{16}O$) are as follows:

Boiling point, 101° C.
Heat of vaporization, 21 calories per gram at the boiling point
Specific heat, 0.26 calories per gram
Density, 1.76
Freezing point, —100° C.

The heat of vaporization varies with the fluorinated compound being used and falls in the range of about 18 to 50 calories per gram.

Referring now to the drawing and FIG. 1 in particular, there is illustrated an electrical apparatus, more specifically the transformer **10** comprising a sealed casing **24** within which is disposed a magnetic core **16** and electrical windings **18** associated therewith, which in this instance are supported on the lower porton of the casing **24**. For the purpose of simplifying the drawing, the leads to the windings **18** and the bushings normally carried by the top or cover portion of the casing **24** are not shown. The windings **18** are subjected to the flow of electrical current therethrough during service which develops heat in the magnetic core **16** and in the windings **18**.

The bottom of the casing **24** is formed to provide a sump **22** in which there is disposed a supply **28** of a fluorinated organic compound, such as perfluorocyclic ether. As illustrated, the supply of the fluorinated compound is so small that it does not come in contact with the magnetic core **16** or the windings **18** although it is to be understood that at least a small portion of

the core 16 and the windings 18 may be at least partially immersed in the fluorinated compound in a particular application.

In order to apply the liquid fluorinated compound or coolant 28 over the core 16 and the windings 18, the pump 42 is disposed for operation to pump the fluorinated compound 28 through a conduit 44 to a spray or flow device 46 from which the fluorinated compound 28 is distributed over said core and windings.

The liquid fluorinated compound 28 sprayed from the device 46 distributes itself as a thin film over the electrical windings 18 and the core 16 and is caused to evaporate freely if the core and coil or windings are hot thereby absorbing heat from the core and coils or windings proportional to the amount of the compound vaporized and its heat of vaporization. The evolved vapors of the compound flow to the wall of the casing 24 where some condensation takes place. The condensate and any excess of liquid compound applied on the core and coils flow back into the sump 22 for recirculation. The vapors, being heavier than the non-condensable gas 26 provided within the casing 24, tend to displace the non-condensable gas in the lower portion of the casing 24 as the windings 18 and the magnetic core 16 heat up during the operation of the transformer 10. In certain applications, it may be advisable to employ a separate radiator or heat exchanger if the walls of the casing 24 are not adequate to dissipate the developed heat to the atmosphere.

The casing 24 of the transformer 10 is initially charged with a quantity of a relatively inert gas 26, substantially non-condensable at moderate pressures and ordinary atmospheric pressures, such as those encountered over the normal operating temperature and pressure ranges of the transformer 10. Examples of preferred suitable non-condensable gases include sulfur hexafluoride, perfluoropropane ($C_3F_8$), and perfluorocyclobutane ($C_4F_8$). Nitrogen, argon, neon, carbon dioxide or the like or a mixture of two or more of these gases may also be employed in certain applications. It has been found that sulfur hexafluoride is particularly suitable for the electrical apparatus as disclosed. Perfluoropropane has a boiling point of approximately −20° C. and perfluorocyclobutane has a boiling point of approximately −4° C. at atmospheric pressure. A charge of a suitable liquid fluorinated compound or liquid fluorocarbon, such as perfluorocyclic ether, is then introduced into the casing 24. The non-condensable gas may be introduced into the casing 24 at substantially atmospheric pressure and atmospheric temperature. When the transformer is cold or inoperative, the liquid fluorinated compound will have only a small partial pressure due to the presence of a small amount of vapors from the liquid compound. As the temperature of the core 16 and the windings 18 increases, the partial pressure of the vapors of the fluorinated compound will increase to thereby drive or push the non-condensable gas, such as sulfur hexafluoride, into the upper portion of the casing 24 since the density of a suitable non-condensable gas, such as sulfur hexafluoride, will normally be less than the density of the vapors of a suitable liquid fluorinated compound.

In order to segregate or separate the non-condensable gas 26 from the vapors of the fluorinated compound 28 in the casing 24 and to limit the pressure of the insulating gas in the casing 24 to substantially a predetermined value as the temperature of the windings 18 and the magnetic core 16 increases, the first auxiliary housing or chamber 75 which contains a quantity of a gas adsorbing solid 98, such as activated carbon, is connected to the upper portion of the casing 24 through the conduit 54 and the first unidirectional regulating valve 110. As previously mentioned, the insulating gas in the casing 24 comprises the vapors of the fluorinated compound 28 and the non-condensable gas 26. The regulating valve 110 is of a general type which responds to the difference between the pressure of the insulating gas in the casing 24 and atmospheric pressure to open and permit the non-condensable gas 26 to flow from the casing 24 into the first auxiliary housing 75 to be gradually absorbed by the gas adsorbing solid 98. In particular, the valve 110 is connected by a pivoted link 114 to the end of a sylphon bellows 112 which controls the operation of the valve 110. One end of the sylphon bellows 112 is open to the conduit 54 on the casing side of the valve 110 whereby the bellows 112 is actuated in response to the vapor pressure within the casing 24. In order to substantially prevent the entrance of the vapors of the fluorinated compound 28 into the auxiliary housing 75, the conduit 54 may be provided with a cooling means, such as a plurality of cooling fins 52, which condenses said vapors as they enter the lower end of the conduit 54 and returns them to the casing 24 for recirculation by the pump 42.

The quantity of gas adsorbing solid disposed in the auxiliary housing 75 is sufficient to adsorb substantially all of the non-condensable gas 26 from the casing 24 of the transformer 10 when the transformer 10 is carrying its full rated electrical load or when the thermal or temperature operating condition of the transformer 10 has reached a maximum value. It is to be understood that other types of suitable gas adsorbing materials may be provided in the auxiliary housing 75, such as those composed of crystalline sodium and calcium alumino-silicates that have been heated to remove their water of hydration, which are known to the art as molecular sieves and which are described in greater detail in the Belgian Patent 534,425 dated December 24, 1954.

In the operation of the transformer 10, the effect of the gas adsorbing solid 98 on the pressure of the insulating gas in the casing 24 is illustrated by the curve 210 in FIG. 2 which shows the variation of the pressure of the insulating gas inside the casing 24 as a function of time during the operation of the transformer 10. It is assumed initially that the transformer 10 is inoperative or deenergized with the temperature of the magnetic core 16 and the associated windings 18 being substantially at a minimum value and with the pressure of the insulating gas inside the casing 24 being also at substantially a minimum value as indicated at 236 in FIG. 2. If the transformer 10 is then energized or put into operation at a point in time indicated at 242 in FIG. 2, the pressure of the insulating gas in the casing 24 gradually increases as the core 16 and the windings 18 gradually heat up during operation with the pressure of the insulating gas increasing to substantially a maximum predetermined value, indicated at 222 in FIG. 2. The valve 110 then opens in response to the pressure of the insulating gas in the casing 24 to permit a portion of the non-condensable gas 26 to flow from the casing 24 into the auxiliary housing 75 where it is adsorbed by the gas adsorbing material 98 to thereby reduce the pressure of the insulating gas in the casing 24 below the substantially predetermined maximum value. As the transformer 10 further heats up during operation, the pressure inside the casing 24 fluctuates as the valve 110 opens and closes in response to pressure changes of the insulating gas in the casing 24, as indicated in FIG. 2, to permit the gas adsorbing solid 98 in the auxiliary housing 75 to gradually adsorb substantially all of the non-condensable gas 26 from the casing 24. It is assumed that when the latter operating condition is reached that the transformer 10 has reached a maximum thermal operating condition with the vapors of the fluorinated compound 28 then comprising substantially all of the insulating gas inside the casing 24 and efficiently cooling the core 16 and the windings 18 substantially in the absence of the non-condensable gas 26.

In order to desorb the non-condensable gas 26 from the gas adsorbing solid 98 after substantially all of said non-condensable gas has been adsorbed by the gas ad-

sorbing solid 98 and to make said non-condensable gas available for return to the casing 24 after the transformer 10 has been subsequently deenergized and the vapors of the fluorinated compound 28 condense, the controller means 80 is provided. In order to sense the substantially complete adsorption of the non-condensable gas 26 by the gas adsorbing solid 98, the controller means 80 may be connected by the control leads 72 to a temperature sensing device 82 and by the control leads 74 to a pressure sensing device 84, which are both disposed inside the auxiliary housing 75 as shown in FIG. 1. When the temperature inside the auxiliary housing 75, as sensed by the temperature sensing device 82, which may be of any conventional type, is below substantially a predetermined value and when the pressure of the non-condensable gas inside the auxiliary housing 75 has increased to substantially a predetermined value, as sensed by the pressure sensitive device 84, indicating that the gas adsorbing solid 98 has substantially completely adsorbed the non-condensable gas 26, the controller means 80 is actuated to heat the gas adsorbing solid 98 and drive off or desorb the non-condensable gas therefrom.

In this instance, the controller means 80 is disposed to supply electric heating current through the conductors 93 and 95 to the terminals 92 and 94, respectively, which then flows through the gas adsorbing solid 98 which is preferably assumed to be an electrical conductor, such as activated carbon, to produce heating by the $I^2R$ losses therein. If the gas adsorbing solid 98 is not electrically conductive, a separate heater may be provided and energized by the controller means 80 in response to the complete adsorption of the non-condensable gas 26 by the gas adsorbing solid 98. It is to be understood that in certain applications, the controller means 80 may be actuated by certain operating conditions in the casing 24 of the transformer 10 in order to sense the complete adsorption of the non-condensable gas 26 by the gas adsorbing material 98.

In order to provide a means for storing the non-condensable gas 26 after it is desorbed from the gas adsorbing material 98 and before it is returned to the casing 24 of the transformer 10, the second auxiliary housing 64 is provided, which in this instance also contains an additional supply of the same substantially non-condensable gas in a liquefied state as indicated at 96. The second auxiliary housing 64 is connected to the first auxiliary housing 75 by the conduit 56 and the second unidirectional regulating valve 120. The lower portion of the second auxiliary housing 64 is connected to the upper portion of the casing 24 through the conduit 66 and the third unidirectional regulating valve 130, as shown in FIG. 1. The second and third regulating valves 120 and 130, respectively, are similar to the first regulating valve 110 as previously described. In particular, the second regulating valve 120 is connected by the pivoted link 124 to the sylphon bellows 122 which controls the operation of the valve 120 in response to the difference in pressure between the pressure of the non-condensable gas in the first auxiliary housing 75 and atmospheric pressure. Similarly, the third regulating valve 130 is connected by a pivoted link 134 to the sylphon bellows 132 which controls the operation of the valve 130 in response to the difference between the pressure in the casing 24 of the transformer 10 and atmospheric pressure.

In the operation of the transformer 10, when the non-condensable gas is desorbed from the gas absorbing material 98 by the controller means 80 and the pressure of said non-condensable gas builds up or increases in the first auxiliary housing 75, the second regulating valve 120 is actuated to an open position by the sylphon bellows 122 when the pressure of the non-condensable gas in the auxiliary housing 75 increases to substantially a predetermined value to permit said non-condensable gas to flow into the second auxiliary housing 64. The pressure at which the second regulating valve 120 opens to permit the flow of the desorbed non-condensable gas from the first auxiliary housing 75 into the second auxiliary housing 64 is above the vapor pressure of said non-condensable gas at the temperature of the second auxiliary housing 96. The non-condensable gas which flows into the second auxiliary housing 64 from the first auxiliary housing 75, therefore, bubbles up through the supply of liquefied non-condensable gas 96 which is disposed in the second auxiliary housing 64 and is also liquefied to reduce the volume or size of the second auxiliary housing 64 which is required to handle a particular quantity of non-condensable gas. It is to be noted that the second auxiliary housing 64 may be provided with suitable cooling means, such as the plurality of cooling fins 62 in order to reduce the pressure necessary to liquefy the non-condensable gas as it enters the second auxiliary housing 64.

If during the operation of the transformer 10, the transformer 10 is first energized and heats up during operation and then is subsequently deenergized as indicated by the point in time at 244 in FIG. 2, and thus gradually cools down, the pressure of the insulating gas inside the casing 24 gradually decreases from the value indicated at 224 in FIG. 2 to the value indicated at 232 in FIG. 2 to thereby reduce the dielectric strength of the insulating gas in the casing 24. In order to prevent the pressure of the insulating gas in the casing 24 from decreasing below substantially a predetermined minimum value and to prevent the corresponding dielectric strength of the insulating gas from also decreasing below a corresponding minimum value, the third regulating relay 130 is actuated by the sylphon bellows 132 to an open position whenever the pressure of the insulating gas in the casing 24 decreases to substantially a predetermined minimum value, as indicated at 232 in FIG. 2. The regulating valve 130 thereby permits a portion of the non-condensable gas in the second auxiliary housing 64, which is then in a liquefied state, to flow back into the casing 24 through the conduit 66 and vaporize to thereby restore the pressure of the insulating gas therein to substantially the desired predetermined minimum value. The transformer 10 is thus restored to the desired initial operating conditions with the dielectric strength of the insulating gas in the casing 24 never decreasing to a value below the desired minimum value. It is to be noted that the second auxiliary housing 64 also contains an excess supply of the non-condensable gas in a liquefied state as indicated at 96, so that in the event of an electric power failure to the control means 80 which is then unable to desorb the non-condensable gas 26 from the gas adsorbing material 98, there will still be sufficient non-condensable gas in the second auxiliary housing 64 to provide the minimum dielectric strength of the insulating gas in the casing 24.

In summary, the casing 24, the first and second auxiliary housings 75 and 64, respectively, form a closed system in which the non-condensable gas is either adsorbed by the gas adsorbing material 98 to limit the pressure of the insulating gas in the casing 24 to substantially a predetermined value or the non-condensable gas is returned to the casing 24 to prevent the pressure of the insulating gas in the casing 24 from falling below substantially a predetermined value. It is to be noted that the gas adsorbing material 98, which is preferably activated carbon to eliminate the necessity for a separate heating device which is energized by the controller means 80, is cyclically reactivated during the heating and cooling of the transformer 10 since the pressure inside the auxiliary housing 75 is normally negligible or a vacuum after the non-condensable gas is desorbed by the controller means 80 and then gradually builds up or increases during the adsorption of the non-condensable gas 26 by the gas adsorbing material 98 during the operation of the transformer 10. It is also to be understood that the second auxiliary housing 96 may be of sufficient capacity so that the non-condensable gas which flows therein from the first auxiliary

housing 75 need not be converted to a liquefied state as shown in FIG. 1 but instead may be maintained in a gaseous state before it is returned to the casing 24 during certain operating conditions of the transformer 10. Finally, it is to be understood that the casing 24 and the first and second auxiliary housing 75 and 64, respectively, may be combined in a unitary structure in certain applications.

The apparatus embodying the teachings of this invention have several advantages. For example, the cooling efficiency of the vapors of a fluorinated compound is obtained more effectively in the absence of the associated non-condensable gas when the vapors of the fluorinated compound are sufficient to provide the necessary dielectric strength and while the pressure of the insulating gas in the casing of an electrical apparatus, as disclosed, is maintained in a predetermined operating range. The casing of a transformer as disclosed may therefore be constructed to withstand a lower predetermined pressure which is maintained in a closed system as described. Finally, the volume and size of each of the auxiliary housings associated with the casing of a transformer as disclosed may be reduced by operating said auxiliary housing at higher predetermined pressures as disclosed.

Since numerous changes may be made in the above described apparatus and circuits and different embodiments of the invention may be made without departing from the spirit and scope thereof, it is intended that all the matter contained in the foregoing description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. An electrical apparatus comprising, an enclosing main casing, a source of heat disposed in said main casing, first means for dissipating the heat from said source comprising a supply of fluorinated liquid coolant, the coolant boiling at a temperature between 50° C. and 225° C. at atmospheric pressure, and second means for applying a layer of said coolant over said source to cool it by evaporation of said coolant to a condensable vapor, the vapors of said coolant having an effective dielectric strength, an insulating gas in said main casing comprising a mixture of a gas which is non-condensable over the normal temperature operating range of said apparatus and the vapors of said fluorinated coolant, the non-condensable gas being volumetrically predominant when said apparatus is cold and increasingly of the vapors of said fluorinated coolant as the temperature of said apparatus increases, third means connected to said casing for adsorbing the non-condensable gas when the pressure of said insulating gas exceeds substantially a first predetermined pressure, fourth means for preventing the vapors of said coolant from entering said third means, fifth means connected between said third means and said casing for desorbing said non-condensable gas, and sixth means for returning the latter desorbed gas to said main casing when the pressure of said insulating gas decreases below substantially a second predetermined value to maintain the dielectric strength of said insulating gas above a minimum value.

2. An electrical apparatus comprising, an enclosing main casing, a source of heat disposed in said main casing, first means for dissipating the heat from said source comprising a supply of fluorinated liquid coolant, the coolant boiling at a temperature between 50° C. and 225° C. at atmospheric pressure, and second means for applying a layer of said coolant over said source to cool it by evaporation of said coolant to a condensable vapor, the vapors of said coolant having an effective dielectric strength, an insulating gas in said main casing comprising a mixture of sulfur hexafluoride which is substantially non-condensable over the normal temperature operating range of said apparatus and the vapors of said fluorinated coolant, the sulfur hexafluoride being volumetrically predominant when said apparatus is cold and increasingly of the vapors of said fluorinated coolant as the temperature of said apparatus increases, third means connected to said casing for adsorbing the sulfur hexafluoride when the pressure of said insulating gas exceeds substantially a first predetermined pressure, fourth means for preventing the vapors of said coolant from entering said third means, fifth means connected between said third means and said casing for desorbing said sulfur hexafluoride, and sixth means for returning the desorbed sulfur hexafluoride to said main casing when the pressure of said insulating gas decreases below substantially a second predetermined value to maintain the dielectric strength of said insulating gas above a minimum value, said third means including a quantity of activated carbon.

3. In an electrical apparatus, the combination comprising, an enclosing main casing, a source of heat disposed in said main casing, first means for dissipating the heat from said source comprising a supply of fluorinated liquid coolant, the coolant boiling at a temperature between 50° C. and 225° C. at atmospheric pressure, and second means for applying a layer of said coolant over said source to cool it by evaporation of said coolant to a condensable vapor, the vapors of said coolant having an effective dielectric strength, an insulating gas in said main casing comprising a mixture of a gas which is non-condensable over the normal temperature operating range of said apparatus and the vapors of said fluorinated coolant, the non-condensable gas being volumetrically predominant when said apparatus is cold and increasingly of the vapors of said fluorinated coolant as the temperature of said apparatus increases, third means connected to said casing for adsorbing the non-condensable gas when the pressure of said insulating gas exceeds substantially a first predetermined pressure, fourth means for preventing the vapors of said coolant from entering said third means, said third means including a quantity of activated carbon, fifth means connected between said third means and said casing for desorbing said non-condensable gas, and sixth means for returning the latter desorbed gas to said main casing when the pressure of said insulating gas decreases below substantially a second predetermined value to maintain the dielectric strength of said insulating gas above a minimum value, said fifth means including means for heating said activated carbon in response to a predetermined operating condition of said apparatus.

4. An electrical apparatus comprising a sealed main casing having an electrical conductor disposed therein which is subject to temperature changes during operation of said apparatus, a gas which is substantially non-condensable over the normal temperature operating range of said apparatus and a vaporizable liquid coolant disposed in said casing, the liquid coolant comprising a fluorinated compound which will vaporize at temperature between 50° C. and 225° C., first means for applying said coolant to said conductor to cool it mainly by evaporation of said coolant, the vapors of the coolant and said gas being intermixed as the conductor heats up in said casing to provide a dielectric medium for insulating said conductor, a first auxiliary housing containing a quantity of material adapted to adsorb said gas, first unidirectional valve means connected between said casing and said first auxiliary housing, said first valve means being responsive to a first predetermined pressure of the dielectric medium in said casing to open and permit said material to adsorb said gas, second means disposed between said casing and said first valve means for substantially preventing the vapors of said coolant from entering said first auxiliary housing, a second auxiliary housing connected between said first auxiliary housing and said casing, second unidirectional valve means connected between said first and second auxiliary housings to open when the pressure of the gas in said first auxiliary housing increases to a second predetermined value, controller means disposed to be responsive to a predetermined operating condition of said apparatus for heating said material and desorbing said gas which

actuates said second valve means to an open position and flows into said second auxiliary housing, and third unidirectional valve means connected between said casing and said second auxiliary housing to be responsive to the pressure of the dielectric medium in said casing, said third valve means being adapted to open when the pressure of the dielectric medium increases to substantially a predetermined third value to permit the gas in said second auxiliary housing to flow back into said casing and provide minimum insulation for said conductor.

5. An electrical apparatus comprising a sealed main casing having an electrical conductor disposed therein which is subject to temperature changes during operation of said apparatus, a gas which is non-condensable over the normal temperature operating range of said apparatus and a vaporizable liquid coolant disposed in said casing, the liquid coolant comprising a fluorinated compound which will vaporize at temperatures between 50° C. and 225° C., first means for applying said coolant to said conductor to cool it mainly by evaporation of said coolant, the vapors of the coolant and said gas being intermixed as the conductor heats up in said casing to provide a dielectric medium for insulating said conductor, a first auxiliary housing containing a quantity of activated carbon adapted to adsorb said gas, first unidirectional valve means connected between said casing and said first auxiliary housing, said first valve means being responsive to a first predetermined pressure of the dielectric medium in said casing to open and permit said activated carbon to adsorb said gas, means disposed between said casing and said first valve means for substantially preventing the vapors of said coolant from entering said first auxiliary housing, a second auxiliary housing connected between said first auxiliary housing and said casing, second unidirectional valve means connected between said first and second auxiliary housings to open when the pressure of the gas in said first auxiliary housing increases to a second predetermined value, controller means disposed to be responsive to a predetermined operating condition of said apparatus for heating said activated carbon and desorbing said gas which actuates said second valve means to an open position and flows into said second auxiliary housing, and third unidirectional valve means connected between said casing and said second auxiliary housing to be responsive to the pressure of the dielectric medium in said casing, said third valve means being adapted to open when the pressure of the dielectric medium decreases to substantially a predetermined third value to permit the gas in said second auxiliary housing to flow back into said casing and provide minimum insulation for said conductor.

6. An electrical apparatus comprising a sealed main casing having an electrical conductor disposed therein which is subject to temperature changes during operation of said apparatus, a gas which is non-condensable over the normal temperature operating range of said apparatus and a vaporizable liquid coolant disposed in said casing, said gas comprising sulfur hexafluoride, the liquid coolant comprising a fluorinated compound which will vaporize at temperatures between 50° C. and 225° C., first means for applying said coolant to said conductor to cool it mainly by evaporation of said coolant, the vapors of the coolant and said gas being intermixed as the conductor heats up in said casing to provide a dielectric medium for insulating said conductor, a first auxiliary housing containing a quantity of material adapted to adsorb said gas, first unidirectional valve means connected between said casing and said first auxiliary housing, said first valve means being responsive to a first predetermined pressure of the dielectric medium in said casing to open and permit said material to adsorb said gas, means disposed between said casing and said first valve means for substantially preventing the vapors of said coolant from entering said first auxiliary housing, a second auxiliary housing connected between said first auxiliary housing and said casing, second unidirectional valve means connected between said first and second auxiliary housings to open when the pressure of the gas in said first auxiliary housing increases to a second predetermined value, controller means disposed to be responsive to a predetermined operating condition of said apparatus for heating said material and desorbing said gas which actuates said second valve means to an open position and flows into said second auxiliary housing, and third unidirectional valve means connected between said casing and said second auxiliary housing to be responsive to the pressure of the dielectric medium in said casing, said third valve means being adapted to open when the pressure of the dielectric medium decreases to substantially a predetermined third value to permit the gas in said second auxiliary housing to flow back into said casing and provide minimum insulation for said conductor.

7. An electrical apparatus comprising, a sealed main casing, first and second auxiliary housings connected to said casing to form a closed system, an electric winding disposed in said casing which heats up when in use, means for dissipating the heat from said winding comprising a supply of fluorinated liquid compound which boils at a temperature between 50° C. and 225° C. and means for applying said liquid compound over said winding to cool said winding mainly by evaporation of said compound to a condensable vapor, an insulating gas in said casing comprising a mixture of gas which is substantially non-condensable over the normal operating range of said apparatus and the vapors of said compound, the insulating gas being volumetrically predominantly composed of said non-condensable gas when said winding is cold and increasingly of the vapors of said compound as said winding heats up, a quantity of a gas adsorbing solid disposed in said first auxiliary housing, a first unidirectional valve connected between said casing and said first auxiliary housing to open when the pressure of the insulating gas in said casing exceeds substantially a predetermined value and permit said gas adsorbing solid to adsorb said non-condensable gas, means disposed between said casing and said first valve for preventing the vapors of said compound from entering said first auxiliary housing, controller means for heating said gas adsorbing solid after said gas adsorbing solid has adsorbed substantially all of said non-condensable gas to desorb the latter gas, a second unidirectional valve connected between said auxiliary housings to open when the pressure of said non-condensable gas exceeds substantially a predetermined value after it is desorbed to permit the latter gas to flow into said second auxiliary housing, and a third unidirectional valve connected between said casing and said second auxiliary housing to open when the pressure of said insulating gas decreases below substantially a predetermined value to permit said non-condensable gas to flow back into said casing and maintain the pressure of said insulating gas at substantially the latter value.

8. An electrical apparatus comprising, a sealed main casing, first and second auxiliary housings connected to said casing to form a closed system, an electric winding disposed in said casing which heats up when in use, means for dissipating the heat from said winding comprising a supply of fluorinated liquid compound which boils at a temperature between 50° C. and 225° C. and means for applying said liquid compound over said winding to cool said winding mainly by evaporation of said compound to a condensable vapor, an insulating gas in said casing comprising a mixture of gas which is substantially non-condensable over the normal operating range of said apparatus and the vapors of said compound, the insulating gas being volumetrically predominantly composed of said non-condensable gas when said winding is cold and increasingly of said vapors as said winding heats up, a quantity of activated carbon disposed in said first auxiliary housing, a first unidirectional valve connected between said casing and said first auxiliary housing to open

when the pressure of the insulating gas in said casing exceeds substantially a predetermined value and permit said activated carbon to absorb said non-condensable gas, means disposed between said casing and said first valve for preventing the vapors of said compound from entering said first auxiliary housing, controller means for heating said activated carbon after said activated carbon has adsorbed substantially all of said non-condensable gas to desorb the latter gas, a second unidirectional valve connected between said auxiliary housings to open when the pressure of said non-condensable gas exceeds substantially a predetermined value after it is desorbed to permit the latter gas to flow into said second auxiliary housing, and a third unidirectional valve connected between said casing and said second auxiliary housing to open when the pressure of said insulating gas decreases below substantially a predetermined value to permit said non-condensable gas to flow back into said casing and maintain the pressure of said insulating gas at substantially the latter value.

9. An electrical apparatus comprising, a sealed main casing, first and second auxiliary housings connected to said casing to form a closed system, an electric winding disposed in said casing which heats up when in use, means for dissipating the heat from said winding comprising a supply of fluorinated liquid compound which boils at a temperature between 50° C. and 225° C. and means for applying said liquid compound over said winding to cool said winding mainly by evaporation of said compound to a condensable vapor, an insulating gas in said casing comprising a mixture of gas which is substantially non-condensable over the normal operating range of said apparatus and the vapors of said compound, the insulating gas being volumetrically predominantly composed of said non-condensable gas when said winding is cold and increasingly of said vapors as said winding heats up, a quantity of a gas absorbing solid disposed in said first auxiliary housing, a first unidirectional valve connected between said casing and said first auxiliary housing to open when the pressure of the insulating gas in said casing exceeds substantially a predetermined value and permit said solid to adsorb said non-condensable gas, means disposed between said casing and said first valve for preventing the vapors of said compound from entering said first auxiliary housing, controller means for heating said solid after said solid has adsorbed substantially all of said non-condensable gas to desorb the latter gas, a second unidirectional valve connected between said auxiliary housings to open when the pressure of said non-condensable gas exceeds substantially a predetermined value after it is desorbed to permit the latter gas to flow into said second auxiliary housing, and a third unidirectional valve connected between said casing and said second auxiliary housing to open when the pressure of said insulating gas decreases below substantially a predetermined value to permit said non-condensable gas to flow back into said casing and maintain the pressure of said insulating gas at substantially the latter value, the pressure at which said second valve opens being above the vapor pressure of said non-condensable gas when the latter gas enters said second auxiliary housing to liquefy the latter gas.

10. In electrical apparatus, the combination comprising, a sealed main casing, first and second auxiliary housings connected to said casing to form a closed system, an electric winding disposed in said casing which heats up when in use, means for dissipating the heat from said winding comprising a supply of fluorinated liquid compound which boils at a temperature between 50° C. and 225° C. and means for applying said liquid compound over said winding to cool said winding mainly by evaporation of said compound to a condensable vapor, an insulating gas in said casing comprising a mixture of sulfur hexafluoride which is substantially non-condensable over the normal operating range of said apparatus and the vapors of said compound, the insulating gas being volumetrically predominantly composed of said sulfur hexafluoride when said winding is cold and increasingly of said vapors as said winding heats up, a quantity of activated carbon disposed in said first auxiliary housing, a first unidirectional valve connected between said casing and said first auxiliary housing to open when the pressure of the insulating gas in said casing exceeds substantially a predetermined value and permit said activated carbon to adsorb said sulfur hexafluoride, controller means for heating said activated carbon after said activated carbon has adsorbed substantially all of said sulfur hexafluoride to desorb the latter gas, means disposed between said casing and said first valve for preventing the vapors of said compound from entering said first auxiliary housing, a second unidirectional valve connected between said auxiliary housings to open when the pressure of said sulfur hexafluoride exceeds substantially a predetermined value after it is desorbed to permit the latter gas to flow into said second auxiliary housing, and a third unidirectional valve connected between said casing and said second auxiliary housing to open when the pressure of said insulating gas decreases below substantially a predetermined valve to permit said sulfur hexafluoride to flow back into said casing and maintain the pressure of said insulating gas at substantially the latter value.

11. An electrical apparatus comprising, a sealed main casing, first and second auxiliary housings connected to said casing to form a closed system, an electric winding disposed in said casing which heats up when in use, means for dissipating the heat from said winding comprising a supply of liquid coolant which boils at a temperature between 50° C. and 225° C. and means for applying said liquid coolant over said winding to cool said winding mainly by evaporation of said coolant to a condensable vapor, an insulating gas in said casing comprising a mixture of gas which is substantially non-condensable over the normal operating range of said apparatus and the vapors of said coolant, the insulating gas being volumetrically predominantly composed of said non-condensable gas when said winding is cold and increasingly of the vapors of said coolant as said winding heats up, a quantity of a gas adsorbing solid disposed in said first auxiliary housing, a first unidirectional valve connected between said casing and said first auxiliary housing to open when the pressure of the insulating gas in said casing exceeds substantially a predetermined value and permit said gas adsorbing solid to adsorb said non-condensable gas, means disposed between said casing and said first valve for preventing the vapors of said coolant from entering said first auxiliary housing, controller means for heating said gas adsorbing solid after said gas adsorbing solid has adsorbed substantially all of said non-condensable gas to desorb the latter gas, a second unidirectional valve connected between said auxiliary housings to open when the pressure of said non-condensable gas exceeds substantially a predetermined value after it is desorbed to permit the latter gas to flow into said second auxiliary housing, and a third unidirectional valve connected between said casing and said second auxiliary housing to open when the pressure of said insulating gas decreases below substantially a predetermined value to permit said non-condensable gas to flow back into said casing and maintain the pressure of said insulating gas at substantially the latter value.

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