

TITLE OF THE INVENTION

DETERIORATION DIAGNOSIS DEVICE AND METHOD FOR SILICONE
FLUID USED FOR AN ELECTRICAL APPARATUS

5 BACKGROUND OF THE INVENTION

[Field of the Invention]

The present invention relates to a deterioration
diagnosis device and method for insulating/cooling silicone
fluid used for an electrical apparatuses.

10 [Prior Art]

Conventionally, insulating oils such as mineral oils
have been used as insulating/cooling medium for electrical
apparatuses such as transformers.

When a flame retardant silicone fluid is used, instead
15 of such mineral oils, as insulating/cooling medium of a
transformer, the fire resistance of the transformer can be
improved, and as a result, its operating temperature can
also be increased, thereby allowing downsizing of an
electrical apparatus using the transformer.

20 However, when silicone fluid is used as
insulating/cooling medium of an electrical apparatus in
order to operate the apparatus at a temperature higher than
conventionally used temperatures, low-molecular-weight and
low-boiling decomposition products are produced by thermal
25 degradation of the silicone fluid.

Generation of a large amount of such decomposition products in silicone fluid presents a problem because they lower the flash temperature (hereinafter referred to as "flash point") of the fluid and therefore render the
5 silicone fluid more likely to be inflamed. The generation of the decomposition products increases with increasing operating temperature of the electrical apparatus.

Japanese Patent Application Laid-open Publication No. Hei 10 (1998)-332682 discloses a technology which evaluates
10 the deterioration level of an electrically insulating oil used in an oil containing electrical apparatus by heating the oil and measuring the chemiluminescence intensity thereof.

Japanese Patent Application Laid-open Publication No. Hei 3 (1991)-187206 discloses a technology in which
15 multiple gas detectors are disposed at upper portions of a tank of an oil containing electrical apparatus such as a transformer and a reactor, and the tank is configured in such a manner that released inflammable gases are
20 efficiently introduced into the gas detectors, thereby ensuring detection of any abnormality such as a dielectric breakdown and local heating of the electrical apparatus.

Japanese Patent Application Laid-open Publication No. Sho 59 (1984)-176683 discloses a technology which measures
25 silicone fluid to obtain its thermogravimetric curve and

solve the curve for the thermogravimetric index, TGI (°C), and determines that the silicone fluid has deteriorated when the index falls below a certain value (325°C).

Japanese Patent Application Laid-open Publication No. Sho 54 (1979)-114290 discloses a technology which analyzes gaseous components released from an insulating oil contained in an electrical apparatus by causing the insulating oil to bubble at room temperature and extracting the gaseous components in the silicone fluid into the vapor phase portion.

Patent Document 1: Japanese Patent Application Laid-open Publication No. Hei 10 (1998)-332682

Patent Document 2: Japanese Patent Application Laid-open Publication No. Hei 3 (1991)-187206

Patent Document 3: Japanese Patent Application Laid-open Publication No. Sho 59 (1984)-176683

Patent Document 4: Japanese Patent Application Laid-open Publication No. Sho 54 (1979)-114290

SUMMARY OF THE INVENTION

When a silicone fluid deteriorates, it produces polymers, (primarily trimers, tetramers and pentamers) of cyclic compounds. It is known that the production of polymers of cyclic compounds increases with the progress of deterioration. Such trimers, tetramers and pentamers have a

low boiling point and are therefore volatile. Initially, when there is no deterioration, the silicone fluid contains almost no polymers of cyclic compounds.

It should be added that such deterioration also
5 produces low-molecular-weight chain compounds. However, such low-molecular-weight chain compounds exist even initially when any deterioration has not progressed. Therefore, some amount of low-molecular-weight chain compounds evaporates even initially.

10 The above-mentioned Japanese Patent Application Laid-open Publication No. Sho 59 (1984)-176683 samples a certain amount of silicone fluid and heats it at a constant heating rate to evaporate low-molecular-weight compounds therein, and then obtains a deterioration index from heating
15 temperatures at which the weights decrease by 10 % and 20 % respectively. However, such a method lacks accuracy because silicone fluid contains low-molecular-weight linear compounds even before use, and therefore the weight decrease or evaporated amount thereof by heating cannot
20 accurately reflect a deterioration.

In addition, the temperature at which the weight decreases by 20 % is as high as 350 - 370°C; however, at such high temperatures, undeteriorated silicone fluid is also thermally decomposed into lower-molecular compounds,
25 which can adversely affect the accuracy of the

deterioration diagnosis.

The inventors have developed the present invention on the basis of experimental confirmation that low-molecular-weight polymers of cyclic compounds contained in silicone fluid can be utilized as an index of thermal deterioration.

That is, quantitative analysis of such polymers of cyclic compounds contained in silicone fluid allows accurate detection of a silicone fluid deterioration.

Major components of low-molecular-weight and low-boiling decomposition products generated by thermal degradation of silicone fluid are cyclic compounds having the same general chemical formula as the silicone fluid. Therefore, it is difficult to analyze a liquid phase sample of silicone fluid and selectively determine the quantity of the decomposed cyclic compounds therein.

An object of the present invention is to provide a deterioration diagnosis device and method for silicone fluid used for an electrical apparatus, capable of accurately and simply diagnosing deterioration of such silicone fluid.

The present invention provides a deterioration diagnosis device for silicone fluid used for an electrical apparatus comprising: an electrical apparatus, a tank for containing the electrical apparatus therein, silicone fluid reserved in the tank and for insulating and/or

cooling the electrical apparatus, a collection pipe for collecting part of the silicone fluid into an exterior of the tank, a gaseous component sampling chamber for heating the silicone fluid collected through the collection pipe in order to evaporate a cyclic compound contained therein, a gas analyzer for quantitatively analyzing the cyclic compound evaporated at the gaseous component sampling chamber, a determination unit for diagnosing the deterioration status of the silicone fluid on the basis of the analysis of the cyclic compound analyzed at the gas analyzer; and a display for displaying the analysis of the cyclic compound analyzed at the gas analyzer and/or the deterioration status of the silicone fluid diagnosed at the determination unit.

The present invention also provides a deterioration diagnosis method for silicone fluid used for an electrical apparatus comprising the steps of: collecting part of the silicone fluid in a tank, which is reserved for insulating and/or cooling an electrical apparatus contained in the tank reserved in a tank for insulating and/or cooling an electrical apparatus contained in the tank into a gaseous component sampling chamber through a collection pipe, heating the collected silicone fluid in order to evaporate a cyclic compound contained therein, quantitatively analyzing the evaporated cyclic compound, determining the

deterioration status of the silicone fluid on the basis of the analysis of the cyclic compound, and displaying the analysis of the cyclic compound and/or the deterioration status of the silicone fluid.

5 Accordingly, the present invention provides a deterioration diagnosis device and method for silicone fluid used for an electrical apparatus, in which the quantity of low-molecular-weight and low-boiling cyclic compounds produced by thermal degradation of the silicone
10 fluid can be efficiently and simply determined on site, thereby enabling an accurate and simple diagnosis of such silicone fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Fig. 1 is a schematic view illustrating a configuration of a deterioration diagnosis device for insulating/cooling silicone fluid used for a silicone fluid containing transformer of an embodiment of the present invention.

 Fig. 2 is characteristic curves illustrating
20 relationships between heating temperatures of silicone fluid and the ionic strengths of polymers of cyclic compounds contained in the silicone fluid.

 Fig. 3 schematically illustrates a monitor screen of the deterioration diagnosis device of the embodiment shown
25 in Fig. 1.

Fig. 4 is a schematic view illustrating a configuration of a deterioration diagnosis device for insulating/cooling silicone fluid used for a silicone fluid containing transformer of another embodiment of the present invention.

5 Fig. 5 is a schematic view illustrating a configuration of a deterioration diagnosis device for insulating/cooling silicone fluid used for a silicone fluid containing transformer of other embodiment of the present invention, which circulates the silicone fluid through the diagnosis
10 device.

Fig. 6 is characteristic curves showing the results of accelerated tests for the thermal deterioration of silicone fluid.

15 DETAILED DESCRIPTION OF THE INVENTION

The deterioration diagnosis device and method for insulating/cooling silicone fluid used for a silicone fluid containing transformer as an electrical apparatus of embodiments of the present invention will now be described
20 with reference to the accompanying drawings.

[Embodiment 1]

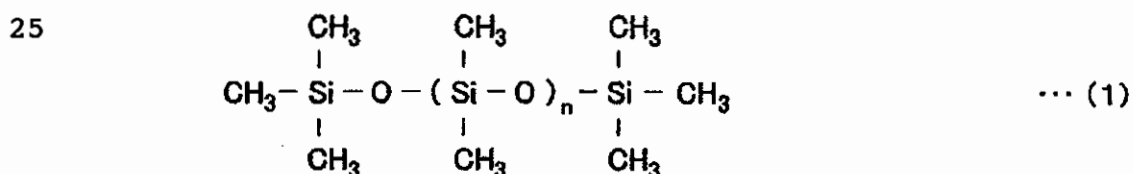
A configuration of a silicone fluid containing transformer is described as an example of a silicone fluid containing electrical apparatus according to an embodiment
25 of the present invention.

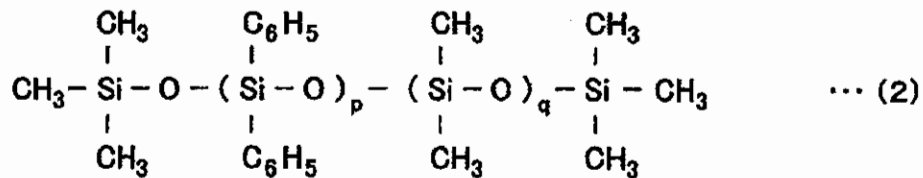
Fig. 1 illustrates a configuration of a deterioration diagnosis device for insulating/cooling silicone fluid used for a silicone fluid containing transformer as an electrical apparatus according to an embodiment of the present invention, which includes: a tank 1; an iron core 2 disposed inside the tank 1; inner and outer windings 3 and 4 around the iron core 2; and an insulating cylinder 5.

The tank 1 contains within it: silicone fluid 6 for insulating and cooling the iron core 2 and the inner and outer windings 3 and 4; and nitrogen gas 7 above the silicone fluid 6.

Outside the tank 1 is placed a cooler 8 for cooling the insulating/cooling silicone fluid 6 reserved in the tank 1, and they are connected to each other by means of circulation pipes 9a and 9b respectively disposed at upper and lower portions thereof.

The insulating/cooling silicone fluid 6 reserved in the tank 1 is a polymer of an organosilicon compound, a chain compound having chemical structure (1) or (2) shown below. The compounds having respective chemical structures (1) and (2), both of which are sometimes also called silicone oil, are basically the same. They may be used alone or as a mixture, but dimethyl silicone fluid having chemical structure (1) is preferred.





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Functionally, the insulating/cooling silicone fluid 6 reserved in the tank 1 is withdrawn, as indicated by the arrow in the figure, from inside of the tank 1 through the upper circulation pipe 9a into inside of the cooler 8 where it is cooled, and then it is returned from the cooler 8 through the lower circulation pipe 9b into inside of the tank 1, where it withdraws Joule's heat generated in the iron core 2 and the inner and outer windings 3 and 4 to cool them.

10

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The iron core 2 is tightened and held by clamps 10a and 10b provided at upper and lower portions, respectively.

Insulators 11 and 12 are fitted to respective upper portions of the inner and outer windings 3 and 4, and insulators 13 and 14 to respective lower portions thereof. Additionally, fluid introduction holes 15 for cooling the iron core 2 are formed at the upper and lower portions along the central axis of the iron core 2.

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The silicone fluid containing transformer as the electrical apparatus according to this embodiment is provided with a breakdown product analyzer of a below-

described configuration for heating the silicone fluid 6 in order to evaporate low-molecular-weight and low-boiling cyclic compounds produced by thermal degradation of the silicone fluid 6 into the vapor phase portion above the liquid surface of the silicone fluid 6, and analyzing the
5 resulting gaseous components.

The deterioration diagnosis device for insulating/cooling silicone fluid used for an electrical apparatus according to this embodiment includes: a
10 collection pipe 16a fitted to a lower portion of the tank 1 and used for collecting the silicone fluid 6 in the tank 1; a gaseous component sampling chamber 17 connected to the collection pipe 16a and used for heating and evaporating the collected silicone fluid 6 and sampling the gaseous
15 components thereof; a gas pipe 18 connected to the gaseous component sampling chamber 17 and used for introducing the gaseous components heated and evaporated at the chamber 17; a gas analyzer 19 connected to the gas pipe 18 and used for analyzing the sampled and introduced gaseous components of
20 the silicone fluid 6; a deterioration determination unit 30 for determining the deterioration status of the silicone fluid on the basis of comparison between the analysis of the gaseous components analyzed by the gas analyzer 19 and a threshold deterioration level; and a display 32 for
25 displaying the analysis of the gaseous components analyzed

by the gas analyzer 19 and/or the silicone fluid deterioration status determined by the deterioration determination unit 30.

Also, outside the gaseous component sampling chamber 17
5 there is provided a heater 20 for heating the collected silicone fluid 6 and evaporating cyclic compounds contained therein. The heater 20 is set to heat the silicone fluid 6 in the gaseous component sampling chamber 17 to approximately 100 to 220°C and preferably approximately 150
10 to 200°C, in order to evaporate low-molecular-weight and low-boiling cyclic compounds produced by thermal degradation of the silicone fluid 6.

Fig. 2 is a set of characteristic curves illustrating relationships between the heating temperatures of the
15 silicone fluid and the ionic strengths of polymers of cyclic compounds contained in the silicone fluid. In order to use the contents of polymers of cyclic compounds contained in the silicone fluid as a barometer for assessing the deterioration of the silicone fluid, the
20 evaporation behaviors of the trimer, tetramer and pentamer contained in the silicone fluid at elevated temperatures were observed. Fig. 2 illustrated the observations.

The observation was carried out by EGA-MS (Evolved Gas Analysis - Mass Spectrometry).

25 In order to increase the measurement sensitivity, there

were used, as specimens, silicone fluids with the addition of the trimer (D3), tetramer (D4) and pentamer (D5) of dimethyl silicone instead of thermally degraded silicone fluids. The specimens were stabilized in He in the analyzer
5 cell, and then continuously heated from 50 to 300°C at a heating rate of 10 °C/min for evaporation while the evaporated gasses being introduced into the mass spectrometer.

Ions having a M/Z ratio (ratio of the mass of an ion (M) to the charge on the ion (Z)) of 207, 281 and 355 were
10 chosen as a representative signature of respective polymers D3, D4 and D5 of cyclic compounds contained in the silicone fluid and their ionic strengths and the total ion current were measured. The silicone fluids were heated from 50 to
15 300°C in He, and the obtained ionic strengths for ions having an M/Z ratio of 207, 281 and 355 are respectively indicated by the alternate long and short dashed line, solid line and dashed line in Fig. 2.

All of the polymers of the cyclic compounds start to
20 evaporate at approximately from 80 to 90°C, and completely vaporize at around 220°C. Therefore, the heating temperature can be set around 100 to 220°C.

Further, limiting the heating temperature range to around 150 to 220°C can reduce the measurement time, and
25 thus provide an efficient measurement. Meanwhile, the

polymers of the cyclic compounds were detected again at temperatures higher than 230 to 250°C. This is probably because such higher temperatures decomposed the silicone fluids and evaporated the resulting decomposed products.

5 The gaseous component sampling chamber 17 of the silicone fluid containing transformer of Fig. 1 collects a predetermined quantity of the silicone fluid 6, and then heats it with the heater 20 to evaporate low-molecular-weight and low-boiling cyclic compounds produced by thermal
10 degradation of the silicone fluid 6 into the vapor phase portion above the liquid surface in the gaseous component sampling chamber 17, thereby obtaining the gaseous components.

 In order to collect a predetermined quantity of the
15 silicone fluid, for example, a substantially constant amount of the silicone fluid is collected by opening a valve 21a for a predetermined constant period of time and then the weight of the collected silicone fluid is measured by weighing means.

20 The gaseous component sampling chamber 17 heats the silicone fluid 6 and evaporates, into the vapor phase portion of the chamber 17, low-molecular-weight cyclic compounds produced by thermal degradation of the silicone fluid 6, and the gaseous cyclic compounds are sent through
25 the gas pipe 18 to the gas analyzer 19, which analyzes and

quantitatively determines only the low-molecular-weight and low-boiling cyclic compounds produced by the thermal degradation. That is, the gas analyzer 19 only measures the combined quantity of the gaseous cyclic compound polymers (trimers, tetramers and pentamers) rather than the total quantity of gaseous components generated by such heating and evaporation.

The cyclic compounds are sent from the gaseous component sampling chamber 17 to the gas analyzer 19, for example, by carrying them on a flowing inert gas such as nitrogen, helium and argon.

Alternatively, in order to efficiently sample the cyclic compounds, an absorbent, which is heatable with a heater, may be placed in the gaseous component sampling chamber 17. In this case, the cyclic compound gaseous components evaporated into the vapor phase portion in the chamber 17 are once absorbed in the absorbent, and then the absorbent is heated to release the absorbed gaseous components, which are then introduced into the gas analyzer 19 by carrying them on an inert gas.

Further, the contents of the trimer, tetramer and pentamer are preassociated with the deterioration levels of the silicone fluid such as the lowering of the flash point thereof, thereby enabling a deterioration diagnosis on the basis of the result of the gas analyzer 19.

For example, the silicone fluid is determined to have deteriorated when the value measured by the gas analyzer or the calculated content of the cyclic compound polymers exceeds a predetermined value.

5 As shown in Fig. 1, the deterioration diagnosis device of this embodiment includes: the determination unit 30; a threshold setting unit 33; the display 32; and a database 31.

10 The determination unit 30 inputs, from the gas analyzer 19, a measured value (analyzed value or calculated content of the cyclic compound polymers) of the gaseous cyclic compounds evaporated from a silicone fluid, and compares it with a silicone fluid deterioration threshold content level for the cyclic compound polymers inputted from the
15 threshold setting unit 33, and then determines that the silicon fluid has deteriorated if the measured value exceeds the threshold level.

20 The determination unit 30 can display the silicone fluid deterioration diagnosis result on the display 32. In addition, the measured value (analyzed value or calculated content of the cyclic compound polymers) of the gaseous cyclic compounds, which is analyzed at the gas analyzer 19 and inputted to the determination unit 30, can be displayed on the display 32 in order to also monitor the quantity of
25 the gaseous cyclic compounds measured by the gas analyzer

19 and/or the content of the polymers calculated from the measurement.

The deterioration of silicone fluid proceeds with the operating years of an electrical apparatus; therefore, in order to accurately monitor such deterioration progress, the quantities of the gaseous cyclic compounds measured by the gas analyzer 19 are inputted, via the determination unit 30, to the database 31 to be stored therein together with the corresponding operating years elapsed. This allows accurate monitoring of a deterioration of a silicone fluid which proceeds with the operating years of an electrical apparatus by retrieving stored historical data from the database 31 to the determination unit 30 and displaying them on the display 30.

The nature of silicone fluid to be diagnosed for the deterioration will now be described with reference to Fig. 6. Fig. 6 is characteristic curves showing the result of an accelerated test for the thermal deterioration of a silicone fluid, in which the abscissa, left-hand and right-hand ordinates represent the elapsed time of a thermal aging test (250°C, 100 hours) of the silicone fluid, the flash point thereof and the content of cyclic compound polymers contained therein, respectively.

As is apparent from Fig. 6, the flash point of a silicone fluid is 300°C or higher before use, but decreases

as the deterioration of the silicone fluid proceeds with increasing aging time.

It can also be seen that the content of cyclic compound polymers (trimers, tetramers and pentamers) contained in
5 the silicone fluid is relatively small before use, but rapidly increases as the deterioration of the silicone fluid proceeds with increasing aging time.

A flash point of a silicone fluid below 200°C may cause an electrical apparatus to catch fire. In consideration of
10 this, a content of cyclic compound polymers at 200°C, for example a value of 3000, is chosen for a silicone fluid deterioration threshold level for comparing with a measured content of such polymers, thereby enabling accurate and simple judgement of silicone fluid deterioration.

15 When the silicone fluid is determined to have deteriorated, the electrical apparatus is stopped or is examined for any abnormality in routine maintenance, or another sample of the silicone fluid is collected to analyze the condition thereof in more detail.

20 Fig. 3 schematically illustrates a monitor screen of the display 32 which displays a progress of a silicone fluid deterioration diagnosed by the determination unit 30. In Fig. 3, the curve marked with triangles plots the content of gaseous cyclic compound polymers which is
25 evaporated from a silicone fluid and measured by the gas

analyzer 19 against the operating time of an electrical apparatus, and the dashed line indicates a suitably predetermined threshold content level (3000) of the polymers for determining a deterioration of the silicone fluid.

Fig. 3 experimentally simulates, in the thermal deterioration accelerated test, transformers A and B operated under relatively high and low loads respectively, in which the abscissa represents aging time in terms of real operating years.

The high and low load simulations were performed at 270°C and 220°C respectively, and the respective contents of cyclic compound polymers were measured as a function of time.

The respective measurements were performed up to an aging time corresponding to an actual operating time of 10 years, and the results were marked with circles and triangles, respectively. The alternate long and short dashed and solid lines respectively represent smooth interpolations/extrapolations of the data points measured for the transformers A and B.

Points where these extrapolation lines cross the threshold content level indicate service life limits of the silicone fluids in the respective transformers. The transformer B can be estimated to have a remaining service

life of about seven years as indicated by L.

In an actual transformer, the silicone fluid contained therein is regularly measured for the content of cyclic compound polymers, and the measured data are stored to
5 obtain a characteristic curve like that shown in Fig. 3, thereby making it possible to predict from an extrapolation of the measured data when to replace the silicone fluid.

Further, when an electrical apparatus such as a transformer is stopped, for example, for routine
10 maintenance, part or all of the silicone fluid is changed depending on the deterioration level which is displayed on the monitor screen of the display 32, thereby forestalling possible failures of such an electrical apparatus.

Also, there can be provided some measure of notifying
15 operators of a deterioration of a silicone fluid when diagnosed, for example by displaying a deterioration status of the silicone fluid diagnosed by the determining unit 32 on the monitor screen of the display 32, thereby facilitating management.

20 For example, when the content of cyclic compound polymers of a silicone fluid exceeds a preset value, the silicone fluid is determined to have deteriorated and the result is then displayed on the monitor screen of the display 32.

25 The frequency of checking deterioration of the silicone

fluid is in the range from once a week to once a month. Therefore, the determination unit 30 can be activated on a regular basis, thereby performing the deterioration diagnosis every predetermined period of time.

5 The determination unit 30 is also provided with a controller for controlling the operations of: the gaseous component sampling chamber 17; the gas analyzer 19; a pump (not shown) and the valve 21a for introducing silicone fluid; and the heater 20 for heating the silicone fluid.

10 With this configuration, the determination unit 30 commands the controller to start the pump every predetermined period of time in order to introduce the silicone fluid 6 in the tank 1 into the gaseous component sampling chamber 17 while energizing the heater 20 to start heating the silicone
15 fluid 6 introduced in the chamber 17, and activate the gas analyzer 19.

 The controller, according to a command from the determination unit 30, first opens the valve 21a to collect the silicone fluid 6 in the tank 1 through the collection
20 pipe 16a connected to the tank 1, and energizes the heater 20 after closing the valve 21a in order to heat the silicone fluid 6 collected in the gaseous component sampling chamber 17 and evaporate cyclic compound polymers contained therein, and then controls the gas analyzer 19 to
25 quantitatively analyze the evaporated cyclic compounds.

It then controls the display 32 to display the content of the cyclic compound polymers analyzed by the gas analyzer 19 or the silicone fluid deterioration status diagnosed by the determination unit 30 on the basis of the analyzed content.

The determination unit 30 then commands the controller to de-energize the heater 20 in the gaseous component sampling chamber 17 after each analysis of the cyclic compounds at the gas analyzer 19 and then purify residuals remaining in the analyzer 19 and the other parts. Since the residual silicone fluid 6 contains a relatively minor amount of decomposition products, it can be returned to the tank 1. Alternatively, it can be discarded because the amount of the silicone fluid 6 required for each measurement is relatively small (e.g., 50 ml).

Furthermore, a single set of a gas analyzer and a diagnosis device can monitor multiple electrical apparatuses (such as a plurality of transformer).

Since the deterioration check frequency of the silicone fluid 6 is in the range from once a week to once a month as described above, multiple electrical apparatuses may be monitored with a single deterioration diagnosis system of silicone fluid used for an electrical apparatus which includes one such analyzer and some sort of flow switch.

Thereby, respective silicone fluids 6 in multiple

electrical apparatuses can be collected to monitor the respective deterioration levels thereof.

The quantitative determination of the gaseous components of the silicone fluid is facilitated when the
5 amount of the silicone fluid 6 collected for each diagnosis is large, while the silicone fluid is easy to heat when it is small.

The amount of the silicone fluid 6 collected for each diagnosis is preferably 1 to 50 ml, but it can be reduced
10 to about 1 to 5 ml while maintaining sufficient measurement accuracy. The residual silicone fluid 6 remaining in the gaseous component sampling chamber 17 after each deterioration diagnosis can be returned to the tank 1 for reuse because they contain no low-molecular-weight
15 compounds which lower the flash point.

In this case, there are preferably provided a return pipe and pump for returning the silicone fluid 6 to the tank 1.

The pump can also be controlled by the above-mentioned
20 determination unit 30 having the controller. In addition, the silicone fluid 6 used for each deterioration diagnosis may be discarded and replenished as needed.

The silicone fluid containing transformer of the above configuration, during its operation, heats the
25 insulating/cooling silicone fluid 6 contained in the tank 1

in order to evaporate, into the vapor phase portion above the liquid surface, the cyclic compounds produced by thermal degradation of the silicone fluid 6 and dissolved therein, and then analyze the resulting gaseous components.

5 This enables an efficient and simple on-site quantitative determination of the cyclic compounds produced by thermal degradation of the silicone fluid 6, and therefore enables a simplified preventive maintenance of the silicone fluid containing transformer.

10 The insulating/cooling silicone fluid 6 contained in the transformer is circulated between the tank 1 and cooler 8 via the circulation pipes 9a and 9b connected therebetween in order to supply the silicone fluid 6 cooled by the cooler 8 to the iron core 2, inner and outer
15 windings 3 and 4, and the other parts disposed inside the tank 1 and cool them; therefore, the kinematics viscosity of the silicone fluid 6 is preferably low, specifically not more than $5.5 \text{ mm}^2/\text{s}$ at 25°C .

In general, the silicone fluid 6 of a lower molecular
20 weight has a lower flash point as well as a lower viscosity. Therefore, the silicone fluid 6 of a lower viscosity has a lower flash point, and probably contains a larger amount of thermally decomposed products having low molecular weights and low boiling points.

25 In addition, when wishing to improve the fire

resistance of a transformer or wishing to downsize an apparatus by increasing its operating temperature, the silicone fluid 6 is preferably flame retardant, and specifically has a flash point more than 250°C.

5 Thus, the insulating/cooling silicone fluid 6 contained in a transformer advantageously has a flash point higher than 250°C and a kinematic viscosity not more than 5.5 mm²/s at 25°C.

10 Furthermore, to the silicone fluid 6 of this embodiment there may be added an additive such as an antistatic agent commonly used in a mineral oil containing transformer.

15 This embodiment provide a deterioration diagnosis device and method for insulating/cooling silicone fluid used for an electrical apparatus, in which the quantity of low-molecular-weight and low-boiling cyclic compounds produced by thermal degradation of the silicone fluid can be efficiently and simply determined on site, thereby enabling an accurate and simple diagnosis of such silicone fluid.

20 [Embodiment 2]

25 Next, a configuration of a deterioration diagnosis device for insulating/cooling silicone fluid used for a silicone fluid containing transformer according to another embodiment of the present invention will be described with reference to Fig. 4. In the silicone fluid containing

transformer according to this embodiment shown in Fig. 4, a gaseous component sampling chamber 17 communicates, via the collection pipe 16a, with the circulation pipe 9b provided at a lower portion of the cooler 8. Since the collection
5 pipe 16a for collecting silicone fluid 6 is connected to the circulation pipe 9b instead of being directly connected to the tank 1, it can be more readily fitted to the transformer.

Since the deterioration diagnosis device for
10 insulating/cooling silicone fluid used for the silicone fluid containing transformer according to this embodiment shown in Fig. 4 has a basically identical configuration to that of the silicone fluid deterioration diagnosis device according to the Embodiment 1 shown in Fig. 1, the
15 description of the common elements will be omitted.

Further, in the silicone fluid containing transformer according to this embodiment shown in Fig. 4, a method for analyzing and quantitatively determining, on-site and during operation, cyclic compounds produced by thermal
20 degradation of the insulating/cooling silicone fluid 6 is the same as that in the Embodiment 1 of Fig. 1, the description thereof will also be omitted herein.

Similarly to Embodiment 1 of Fig.1, the above-described embodiment also provides the deterioration diagnosis device
25 and method for insulating/cooling silicone fluid used for

the electrical apparatus, in which the quantity of low-molecular-weight and low-boiling cyclic compounds produced by thermal degradation of the silicone fluid can be efficiently and simply determined on site, thereby enabling
5 an accurate and simple diagnosis of such silicone fluid.

[Embodiment 3]

Fig. 5 illustrates a silicone fluid deterioration diagnosis device for insulating/cooling silicone fluid used for an electrical apparatus according to other embodiment
10 of the present invention. This embodiment circulates the silicone fluid 6 through an analyzer. Additionally, this embodiment collects the silicone fluid 6 from the main body of a tank 1 and returns it to the circulation pipe 9b of the cooler 8. The pump 28 for circulating the silicone
15 fluid 6 is provided in the pipe 16a.

The valves 21a and 21b, respectively provided in the pipes 21a and 21b, are opened to circulate the silicone fluid 6 through the pipes connected to the gaseous component sampling chamber 17, and are then closed after
20 residual silicon fluid remaining in the chamber 17 has been sufficiently replaced by a new silicon fluid 6 collected for a next measurement, and thereafter the predetermined amount of the silicon fluid 6 in the chamber 17 is heated and evaporated with a heater 20 in order to sample the
25 gaseous components.

Then, the gaseous components sampled at the chamber 17 are analyzed by the gas analyzer 19 to measure the content of cyclic compound polymers therein. The measured value (analyzed value or calculated content of the cyclic
5 compound polymers) of the gaseous components analyzed at the gas analyzer 19 is then compared with a silicone fluid deterioration threshold content level of the polymers inputted from a threshold setting unit 33, and the silicon fluid is determined to have deteriorated if the measured
10 value exceeds the threshold level.

The silicone fluid deterioration status diagnosed is then outputted from the determination unit 30 to be displayed on a display 32.

In addition, the measured value (analyzed value or
15 calculated content of the polymers) of the gaseous cyclic compounds, which is analyzed at the gas analyzer 19 and inputted to the determination unit 30, may be displayed on the display 32 in order to also monitor the quantities of the gaseous cyclic compounds or the content of the cyclic
20 compound polymers calculated from the measurement.

The silicone fluid 6 after each measurement can be returned to the tank 1 by opening the valves 21a and 21b because it has only lost the polymers of cyclic compounds.

Meanwhile, the silicone fluid 6 may be collected from
25 the circulation pipe 9b, but it more advantageously is

collected from a circulation pipe 9a or an upper portion of the tank 1 in order to reduce the heat applied for each analysis.

5 In addition, the silicone fluid 6 is advantageously returned to the circulation pipe 9a or 9b, because the flow speed of the silicone fluid 6 is higher in the circulation pipe causing a natural circulation therethrough and thereby some pumps for the circulation purpose can be spared.

10 Furthermore, this embodiment adds a function of informing operators of results obtained at the silicone fluid deterioration diagnosis device. The display 32 not only displays the measured values (calculated content of the cyclic compound polymers) of the gaseous cyclic compounds analyzed by the gas analyzer 19, but also
15 displays diagnosis results obtained at the determination unit 30 which compares a measured content of the cyclic compound polymers contained in a silicone fluid with a threshold level thereof and determines that the silicone fluid has deteriorated if the measured content exceeds the
20 threshold level, thereby allowing operators to monitor, on the determination unit 30, measured quantities of the gaseous cyclic compounds as well as diagnosis results obtained at the silicone fluid deterioration diagnosis device.

25 A supervisor can check for any deterioration of the

silicone fluid 6 and maintenance the apparatus according to the present embodiment. For example, there may be provided an alarm device or the like for issuing an alarm when an evaporated quantity of the cyclic compound polymers exceeds
5 a preset value, that is, the silicone fluid 6 is determined to have deteriorated.

The threshold level preset in the threshold setting unit 33 is chosen, for example, by considering relationships between measured quantities of the cyclic
10 compounds in deteriorated silicone fluids and properties thereof such as electrical conductivity and ignition point.

Furthermore, while any commercially available valve and alarm device may be employed, preferably the valves used are opened and the alarm used is issued when the power goes
15 off.

This embodiment achieves to provide a deterioration diagnosis device and method for insulating/cooling silicone fluid used for an electrical apparatus, in which the quantity of low-molecular-weight and low-boiling cyclic
20 compounds produced by thermal degradation of the silicone fluid can be efficiently and simply determined on site, thereby enabling an accurate and simple diagnosis of such silicone fluid.

Next, an exemplary operation pattern of a silicone
25 fluid containing electrical apparatus equipped with a

deterioration diagnosis device of silicone fluid shown in Figs. 1, 4 and 5 will be described. Diagnosis by the deterioration diagnosis device of silicone fluid can be performed at a predetermined frequency such as once a week and once a month, or on a regular and frequent basis.

An example of regularly scheduled diagnosis using the deterioration diagnosis device of silicone fluid will be described below. The operation of the deterioration diagnosis device of silicone fluid can be broadly divided into four steps: preparation, measurement, cleaning and standby.

Table 1

	OPERATION FOR DETERIORATION DIAGNOSIS	VALVE (V1, V2)	HEATER (H)	TIME
PREPARATION	Change of Silicone Fluid in Pipes	OPEN	OFF	10 min
SAMPLING & MEASUREMENT	Heating of a Constant Amount of Silicone Fluid, Evaporation of Cyclic Compounds and Measurement of the Quantity thereof	CLOSE	ON	10 min
CLEANING	Drainage of Measured Silicone Fluid out of System or Return thereof into Tank	CLOSE	OFF	15 min
INACTIVE (STANDBY)	Not Operating	CLOSE	OFF	Predeter- mined Time

The time required for each step in Table 1 is adjustable depending on the configuration of piping, frequency of checking the silicone fluid, period of use thereof, etc. In the case where the measurement is

performed at a predetermined time interval, multiple electrical apparatuses can be monitored by connecting them via multiple pipes to a single analyzer and switching between flow paths.

5 The step of preparing for a measurement of the silicone fluid 6, according to a command from the determination unit 30, starts pumps and opens valves, thereby circulating the silicone fluid 6 contained in the collection pipe connected to the tank 1 and the gaseous component sampling chamber 17
10 for collecting the silicone fluid 6.

 The step of measuring the silicone fluid 6, according to a command from the determination unit 30, stops the pumps, closes the valves and energizes the heater 20 in order to heat a constant amount of the silicone fluid 6
15 collected in the gaseous component sampling chamber 17 and evaporate cyclic compounds contained therein; then analyzes the evaporated gaseous cyclic compounds at the gas analyzer 19; and thereafter diagnoses, at the determination unit 30, a deterioration status of the silicone fluid 6 on the basis
20 of the measured values of the gaseous cyclic compounds.

 The cleaning step, according to a command from the determination unit 30, de-energizes the heater 20, and purifies and removes the residual silicone fluid and components thereof remaining in the analyzer and the other
25 parts. Since the residual silicone fluid after each

diagnosis has had the cyclic compound polymers removed therefrom and therefore contains a relatively minor amount of decomposition products, it may be returned to the tank 1. Alternatively, the silicone fluid 6 may be discarded after
5 each measurement because the amount thereof required for each measurement is relatively small (1 to 50 ml).

An administrator is informed, by a command from the determination unit 30, of a possible deterioration of the silicone fluid 6 on the basis of information detected at
10 each measurement, or the silicone fluid containing electrical apparatus is controllably stopped, thereby enabling an efficient abnormality detection and preventive maintenance of a silicone fluid containing electrical apparatus.

15 Use of the above-described operation pattern provides a deterioration diagnosis device and method for insulating/cooling silicone fluid used for an electrical apparatus, in which the quantity of low-molecular-weight and low-boiling cyclic compounds produced by thermal
20 degradation of the silicone fluid can be efficiently and simply determined on site, thereby enabling an accurate and simple diagnosis of such silicone fluid.

WHAT IS CLAIMED IS

1. A deterioration diagnosis device for silicone fluid used for an electrical apparatus comprising:

an electrical apparatus;

5 a tank for containing the electrical apparatus thereinside;

silicone fluid reserved in the tank for insulating and/or cooling the electrical apparatus;

10 a collection pipe for collecting part of the silicone fluid into an exterior of the tank;

a gaseous component sampling chamber for heating the silicone fluid collected through the collection pipe in order to evaporate a cyclic compound contained therein;

15 a gas analyzer for quantitatively analyzing the cyclic compound evaporated at the gaseous component sampling chamber;

a determination unit for diagnosing the deterioration status of the silicone fluid on the basis of the analysis of the cyclic compound analyzed at the gas analyzer, and

20 a display for displaying the analysis of the cyclic compound analyzed at the gas analyzer and/or the deterioration status of the silicone fluid diagnosed at the determination unit.

25 2. The deterioration diagnosis device for silicone fluid used for an electrical apparatus according to Claim 1,

wherein the gaseous component sampling chamber has a function of heating the collected silicone fluid to a temperature of 100°C to 220°C.

3. The deterioration diagnosis device for silicone
5 fluid used for an electrical apparatus according to Claim 1, wherein the determination unit diagnoses the deterioration status of the silicone fluid on the basis of comparison between the analysis of the cyclic compound analyzed at the gas analyzer and a deterioration threshold level.

10 4. The deterioration diagnosis device for silicone fluid used for an electrical apparatus according to Claim 1, wherein the electrical apparatus is one of a transformer, a reactor, a voltage regulator, a capacitor and a resistor.

5. The deterioration diagnosis device for silicone
15 fluid used for an electrical apparatus according to Claim 1, further comprising:

a return pipe for returning a residual silicone fluid remaining in the gaseous component sampling chamber to the tank therethrough; and

20 a pump provided in the return pipe and for returning the residual silicone fluid to the tank.

6. The deterioration diagnosis device for silicone
fluid used for an electrical apparatus according to Claim 5, further comprising a controller for: starting and stopping
25 the pump; heating, while the pump is stopped, the gaseous

component sampling chamber in order to evaporate the cyclic compound; and commanding the gas analyzer to quantitatively analyze the cyclic compound.

7. The deterioration diagnosis device for silicone fluid used for an electrical apparatus according to Claim 1,
5 further comprising:

a cooler for cooling the silicone fluid in the tank;
and

a circulation pipe for communicating the tank and the
10 cooler and circulating the silicone fluid therethrough; and
the collection pipe for collecting the silicone fluid is
connected to the circulation pipe.

8. The deterioration diagnosis device for silicone fluid used for an electrical apparatus according to Claim 1,
15 wherein the silicone fluid has a flash point not lower than
250°C and a kinematic viscosity not more than 55 mm²/s at
25°C.

9. A deterioration diagnosis method for silicone fluid used for an electrical apparatus comprising the steps of:

20 collecting part of the silicone fluid in a tank, which
is reserved for insulating and/or cooling an electrical
apparatus contained in the tank reserved in a tank for
insulating and/or cooling an electrical apparatus contained
in the tank into a gaseous component sampling chamber
25 through a collection pipe;

heating the collected silicone fluid in order to
evaporate a cyclic compound contained therein;

quantitatively analyzing the evaporated cyclic
compound;

5 determining the deterioration status of the silicone
fluid on the basis of the analysis of the cyclic compound;
and

displaying the analysis of the cyclic compound and/or
the deterioration status of the silicone fluid.

10 10. The deterioration diagnosis method for silicone
fluid used for an electrical apparatus according to Claim 9,
wherein the collected silicone fluid is heated to a
temperature of 100°C to 220°C.

15 11. The deterioration diagnosis method for silicone
fluid used for an electrical apparatus according to Claim 9,
wherein the determination step diagnoses the deterioration
status of the silicone fluid on the basis of comparison
between the analysis of the cyclic compound and a
deterioration threshold level.

20 12. The deterioration diagnosis method for silicone
fluid used for an electrical apparatus according to Claim 9,
wherein the electrical apparatus is one of a transformer, a
reactor, a voltage regulator, a capacitor and a resistor.

25 13. The deterioration diagnosis method for silicone
fluid used for an electrical apparatus according to Claim 9,

wherein the silicone fluid has a flash point not lower than 250°C and a kinematic viscosity not more than 55 mm²/s at 25°C.