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(54) REPAIRING GEL INSULATION OF ELECTRICAL DEVICES

(57) The present disclosure relates to a method of repairing an electrical insulator (3) of an electrical device (1) after electrical breakdown of said insulator. The insulator comprises an oil-based thermo-reversible gel (4) comprising a thickener. The method comprises operating the electrical device at an operating temperature below a transition temperature of the gel, at which the gel is in its solid form. The method also comprises, during the operating of the device, determining electrical breakdown of the insulator. The method also comprises, after the determining, increasing the temperature of the insulator to a repair temperature, which is above the transition temperature of the gel, whereby the gel transitions to its liquid form. The method also comprises, after the increasing of the temperature, reducing the temperature of the insulator to below the transition temperature, whereby the gel returns to its solid form. The method also comprises, after the reducing of the temperature, re-operating the electrical device at an operating temperature below the transition temperature of the gel.

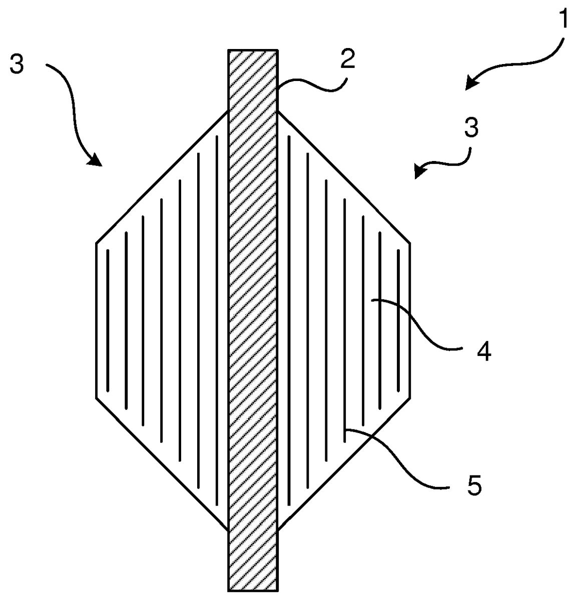

Fig. 1

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to gel insulated electrical devices.

BACKGROUND

[0002] Breakdown of a dry insulation of an electrical device or component, e.g. instrument transformer, power transformer, bushing etc., results in formation of a breakdown channel formed through the insulation and thus device failure. The device is irreparably damaged and cannot be reused. The breakdown of epoxy or silicone insulation, which are the common choices of dry insulation, creates irreversible loss of insulation properties. Additionally, due to specific features of epoxy resin, recycling of metal parts after failure of the device is difficult and expensive. Any defect at manufacturing or processing of the device may result in device failure at type or routine test.

SUMMARY

[0003] It is an objective of the present invention to provide a method of repairing electrical insulation of an electrical device after breakdown of said insulation. This is achieved by using a thermo-reversible gel as insulation material, wherein the gel can be heated to above a transition temperature of the gel to transition from a solid form to a liquid form in which the breakdown channel formed by the breakdown is collapsed and the insulation is repaired, after which the gel is cooled to below the transition temperature to transition from its liquid form to its solid form once again.

[0004] According to an aspect of the present invention, there is provided a method of repairing an electrical insulator of an electrical device after electrical breakdown of said insulator. The insulator comprises an oil-based thermo-reversible gel comprising a thickener. The method comprises operating the electrical device at an operating temperature below a transition temperature of the gel, at which the gel is in its solid form. The method also comprises, during the operating of the device, determining electrical breakdown of the insulator. The method also comprises, after the determining, increasing the temperature of the insulator to a repair temperature, which is above the transition temperature of the gel, whereby the gel transitions to its liquid form. The method also comprises, after the increasing of the temperature, reducing the temperature of the insulator to below the transition temperature, whereby the gel returns to its solid form. The method also comprises, after the reducing of the temperature, re-operating the electrical device at an operating temperature below the transition temperature of the gel.

[0005] Thus, a solid electrical insulator of an electrical device can be repaired and reused.

[0006] Further, the use of the gel insulation allows the processing of the insulation material to be simpler, faster and cheaper. Advanced process equipment may not be required. The cost of material may be lower related to resin such as epoxy. Therefore, this solution renders possible reduction of labour and material costs.

[0007] Moreover, if a device failure is caused by an internal defect in active part (and device cannot be regenerated) the recycling process of metal parts is very easy compared with if solid epoxy or other resin is used and thus stuck to the metal parts.

[0008] In terms of safety and environmental aspects, the gel may have high flash and fire points, e.g. above 200°C, depending on the oil used for preparation of the gel.

[0009] Further, the gel insulation material does not risk to be absorbed into the soil or get into the waste and/or ground water upon leakage since the gel will solidify upon cooling and is easily recovered in solid form.

[0010] It is to be noted that any feature of any of the aspects may be applied to any other aspect, wherever appropriate. Likewise, any advantage of any of the aspects may apply to any of the other aspects. Other objectives, features and advantages of the enclosed embodiments will be apparent from the following detailed disclosure, from the attached dependent claims as well as from the drawings.

[0011] Generally, all terms used in the claims are to be interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise herein. All references to "a/an/the element, apparatus, component, means, step, etc." are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, step, etc., unless explicitly stated otherwise. The steps of any method disclosed herein do not have to be performed in the exact order disclosed, unless explicitly stated. The use of "first", "second" etc. for different features/components of the present disclosure are only intended to distinguish the features/components from other similar features/components and not to impart any order or hierarchy to the features/components.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Embodiments will be described, by way of example, with reference to the accompanying drawings, in which:

Fig 1 schematically illustrates an electrical device, here in the form of a HV bushing, with a gel insulation, in accordance with embodiments of the present invention.

Fig 2 is a schematic graph showing the complex viscosity at different temperatures for an oil based gel, where the gel is solid at temperatures below a transition temperature (corresponding to a knee in the graph), and liquid at temperatures above said transition temperature, in accordance with embodiments of the present invention.

Fig 3 is a schematic flow chart of an embodiment of the method of the present invention.

DETAILED DESCRIPTION

[0013] Embodiments will now be described more fully hereinafter with reference to the accompanying drawings, in which certain embodiments are shown.

[0014] However, other embodiments in many different forms are possible within the scope of the present disclosure. Rather, the following embodiments are provided by way of example so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art. Like numbers refer to like elements throughout the description.

[0015] The use of electrically insulating thermo-reversible gels are known for impregnating power cable insulation, where the gel can be made sufficiently soft and resilient to allow the cable to be flexible.

[0016] WO 97/04466 relates to a High-Voltage Direct Current (HVDC) power cable comprising an insulation of a plurality of permeable tapes wound around the conductor. An impregnating compound fills all voids among the tape layers. The impregnating compound has a very steep slope of change of viscosity characteristics, the viscosity being high with a solid gel type structure at temperatures equal to and below the maximum operating temperature of the cable and being low with a thin liquid type structure at higher temperatures at which impregnation takes place. Preferably, 95% of the impregnating compound consists of alkane chains with chain lengths above 15 carbon units but no more than 2% of the chains have chain lengths above 28 carbon units.

[0017] WO 99/33066 discloses a dielectric gelling composition, exhibiting a thermo-reversible liquid-gel transition at a transition temperature, wherein the gel comprises an oil and a gelator with a block copolymer. The gelling composition is used as an impregnant in an insulated direct current (DC) cable having at least one conductor and an impregnated insulation system. The insulation system comprises a solid electrically insulating dielectric part with a porous, fibrous and/or laminated structure impregnated with the dielectric gelling composition.

[0018] US 6,391,447 relates to a method for manufacture of an electric device having at least one conductor and a porous, fibrous and/or laminated electrically insulating dielectric system comprising a solid electrically insulating part impregnated with a dielectric fluid, wherein the method comprises impregnating with a dielectric fluid, wherein a gelling additive is added to impart a high viscosity and elasticity to the fluid at conditions for which the device is designed to operate under.

[0019] US 8,134,089 discloses the use of an electrically insulating filler comprising a gel for an electrical device, e.g. a bushing.

[0020] However, none of these documents are concerned with the problem of repairing a solid insulation after breakdown thereof.

[0021] Figure 1 illustrates an embodiment of a an electrical device 1, here a High-Voltage (HV) bushing, comprising an insulator 3, here in the form of a condenser core, surrounding a conductor 2. The bushing 1 may e.g. be for allowing the conductor 2 to pass through a wall, e.g. of a power transformer, converter or other electrical equipment. The insulator 3 comprises an insulating material 4 comprising a thermo-reversible gel, e.g. by itself or impregnating a permeable solid insulation material. The permeable solid material may e.g. be cellulose based such as a paper material, e.g. craft or crepe paper or board, or synthetic e.g. aramid-based such as NOMEX™, or a combination thereof, which can be impregnated by the gel in liquid form. The gel is a mixture of an oil with a thickener, and optional additives such as an anti-oxidant. Optionally, the insulator 3, e.g. condenser core, comprises a plurality of electrically conducting foils 5, floating in the insulation material 4 for modifying the electrical field formed by the conductor 2 in the electrical when in use, e.g. of aluminium (Al) or copper (Cu). Typically, the insulator 3 is encased in a shell (not shown).

[0022] The oil may be any electrically insulating oil, e.g. mineral oil, aromatic oil, ester oil and/or paraffinic oil, e.g. iso-paraffinic oil, or a mixture thereof.

[0023] The thickener may be a polymeric thickener e.g. SEPTON styrene thermoplastic elastomer containing block copolymers - e.g. SEPTON™ 1000-SERIES (SEP), SEPTON™ 4000-SERIES (SEEPS) from Kuraray. As an example, a thickener comprising or consisting of SEEPS™ 4099 (a tri-block copolymer consisting of polystyrene-b-poly(ethylene-ethylene/propylene)-b-polystyrene) and/or SEP™ 1020 (a di-block copolymer consisting of polystyrene-b-poly(ethylene/propylene)) may be used. However, this is non-exhaustive and the skilled person recognizes that other polymeric thickeners may be used. The thickener may be present in an amount of at most 10 wt% of the gel (4), e.g. 1-5 wt%.

[0024] In some embodiments, the gel 4 may, in addition to the oil and thickener, one or several additives, such as an anti-oxidant as mentioned above, or any other additive may be added, e.g. up to 1 wt% of the gel 4. For instance, it has been realised that boron nitride (BN), e.g. 2D hexagonal BN (h-BN) improves the electrical properties of the gel, and reduces problems with oxidation. By suspending particles, e.g. nano-structures, of BN in the gel 4, the particles remain dispersed.

[0025] The electrical device may be any electrical device with solid insulation, and a bushing is only an example thereof. Other examples include, but are not limited to, instrument transformers, power transformers e.g. current and voltage transformers, capacitors and cable endings. In most oil insulated devices, the oil can be replaced with an oil-based gel as per the present invention. However, devices with impregnated paper may not be preferred since paper is degraded in high temperatures. Instead of paper, synthetic fibres may be used for a solid insulation impregnated with the gel, e.g. in a mesh material similar as used for Resin Impregnated Synthetic (RIS) insulators. The insulator 3 may provide insulation to ground in the electrical device 1.

[0026] The operating voltage of the electrical device 1 may preferably be medium voltage (MV), up to 72 kV, but high voltage (HV) applications above 72 kV are possible as well. The insulating gel 4 may act as a major insulation (between the high potential and ground) of the electrical device 1.

[0027] Figure 2 illustrates the change in viscosity over a temperature range of an oil-based gel. The gel 4 should have a high viscosity (be in its solid form) at operating temperatures of the electrical device 1 but should also have a relatively low viscosity (be in its liquid form) at a regeneration temperature where any breakdown channels are melted together. This makes the gel thermoreversible, being in a solid form at temperatures below a transition temperature and in a liquid form at temperatures above said transition temperature, forming a knee in the viscosity curve of figure 2. In the example of figure 2, the gel has a complex viscosity above 10 Pa·s (is in its solid form) below about 50°C and a complex viscosity below 0.01 Pa·s (is in its liquid form) above about 90°C.

[0028] The preferred viscosity of the gel 4 at the operating temperature of the electrical device 1, as well as the transition temperature and preferred viscosity of the gel when in liquid form (when the insulator (3) is repaired, may vary depending on the application. As an example, the gel may have a viscosity in solid form, e.g. below 90°C, of at least 10 Pa·s, and a viscosity in liquid form, e.g. above 110°C, of at most 0.1 Pa·s, e.g. for an operating temperature of the electrical device of 80°C.

[0029] The insulator 3 comprises a gel 4 based on an insulating oil, e.g. mineral oil, aromatic oil, ester oil and/or paraffinic oil, e.g. iso-paraffinic oil. The gel is formed by mixing of the oil with a polymeric thickener (e.g. thermoplastic elastomer consisting block copolymers) at an elevated temperature (e.g. above about 100°C). The polymeric thickener thus dissolves in the oil. The gel increases its viscosity while cooling down until it has passed its transition temperature and becomes solid. The process is fully reversible. After heating up above the transition temperature, the gel returns to liquid form. Thanks to that, the oil-based gel has repairable and self-healing properties. That feature makes the gel an interesting alternative to other dry insulation materials. The viscosity and transition temperature of the gel can be adjusted by the amount and type of thickener added to the oil. The more thickener, the higher transition temperature (corresponding to the knee in figure 2).

[0030] Regenerating properties of the gel have been proven at laboratory scale by testing number of small scale samples and then confirmed by Alternating Current (AC) and Lightning Impulse (LI) tests on concept demonstrator of TJC4 voltage transformer.

[0031] The small scale test samples contained two flat epoxy coated electrodes of 25 mm and 75 mm diameters insulated by a 2 mm thick layer of the gel. The samples broke at average level of ca. 88 kV. Then, the samples were regenerated by heating the gel above its transition temperature. When the temperature was high enough, the gel became liquid and the breakdown channel disappeared due to convection and diffusion. After regeneration, the samples were subjected to breakdown voltage test once again. In the second test, the average breakdown voltage was of ca. 53 kV.

[0032] It is noted that in the test samples a small amount of the gel was used. At regeneration process, the carbonized particles coming from the breakdown channel dispersed in the gel near the inter-electrode area. If the particles stay in the high electric field intensity area, they will be a source of Partial Discharges (PDs), leading to failure. Therefore, the regeneration quality may be improved if a larger amount of the gel is used, resulting in a thicker layer of gel 4 around the conductor 2, e.g. as in case of real scale Medium Voltage (MV) Instrument Transformer (IT). The regeneration quality may be improved if the gel in its liquid form is stirred to disperse the carbonized particles to a larger extent.

[0033] The repairable properties of the gel 4 have been confirmed at real scale on the basis of a TJC4 MV Voltage Transformer (VT) of 12 kV. The voltage transformer was filled with the gel comprising 3 wt% of thickener and then subjected to AC withstand and LI tests. The history of the gel insulated TJC4 VT was as follows:

- Filling with gel: 3wt% of thickener,
- 28 kV AC withstand test and PD measurement - passed,
- LI 75 kV test - passed,
- Cold test (16 h at -40°C),
- 28 kV AC withstand test and PD measurement - passed,
- LI 75 kV test - failed,
- Regeneration of insulation at 150°C,
- 28 kV AC withstand test and PD measurement - passed,
- LI 75 kV test - failed.

[0034] After regeneration, the transformer insulation gel 4 recovered its properties and passed the AC withstand and PD tests, but then failed at the LI test.

[0035] Dissection of the transformer after tests showed that breakdown occurred between the sharp edge of the HV shield and grounded core in the high electric field intensity area. The reason for breakdown was not related to carbonized particles after regeneration process but to sharp edges of the HV shield.

[0036] The gel in liquid state has good penetrating and impregnating properties and may be used together with permeable solid insulation, e.g. paper. The gel easily penetrates and fills voids in the permeable solid insulation, as well as between non-permeable interlayer foils within primary winding of the voltage transformer, improving its insulating properties.

[0037] The gel 4 may have neutral or at least very limited environmental impact thanks to its self-solidifying properties. If the gel in liquid state (e.g. of a temperature above 100°C, depending on the thickener content) is spilled onto the ground (leakage), it solidifies before penetrating into the soil.

[0038] Figure 3 is a schematic flow chart of an embodiment of the method of the present invention. The method is for repairing an electrical insulator 3 of an electrical device 1 after electrical breakdown of said insulator, wherein the insulator comprises an oil-based thermo-reversible gel 4 comprising a thickener, as discussed herein.

[0039] The electrical device 1 is operated M1 at an operating temperature below a transition temperature of the gel 4, at which the gel is in its solid form. For instance, the operating temperature may be up to 80°C, e.g. within the range of 50-80°C or 30-60°C, depending on application and voltage or current rating of the electrical device. The gel 4 can be regarded as solid when having a complex viscosity above 10 Pa·s, and as liquid when having a complex viscosity of less than 0.1 or 0.01 Pa·s. The transition temperature may e.g. be within the range of 60-110°C, e.g. within the range of 60-90°C or 80-110°C, depending on application and voltage or current rating of the electrical device.

[0040] During the operating M1 of the device 1, electrical breakdown of the insulator 3 is determined M2. There are different methods for determining breakdown of the electrical device 1, e.g. by measuring the resistance over the insulator 3 or by applying voltage to the device 1 and measuring the current flow between the high potential in the device and ground.

[0041] After the determining M2 that the insulator has broken down, the temperature of the insulator 3 is increased M3 to above the transition temperature of the gel, e.g. to above 90 or 110°C, whereby the gel 4 transitions to its liquid form. This increased temperature may be called the repair temperature and may e.g. be at least 90 or 110°C, e.g. up to 150°C, depending on the transition temperature of the gel. The time period during which the repair temperature of the insulator is maintained depends on the application, particularly on the volume of the insulating gel 4 to be heated above the transition temperature from solid to liquid form. A larger volume of the insulator 3 may require a longer time for all the gel 4 to transition to its liquid form. For instance, the time period at the repair temperature may be within the range of from 5 or 8 hours (e.g. for a volume of the gel below 10 litres) to more than 10 hours, e.g. at least 20 h, (for larger volumes of gel 4). The time needed for repairing breakdown channels in the gel may also depend on the viscosity of the gel at the repair temperature. In some embodiments, the repair process may be improved by e.g. stirring the gel 4 in its liquid form, oil treatment, filtering, or even regeneration, if required. As the gel is in its liquid form, any breakdown channel(s) formed in the insulator 3 by the electrical breakdown is collapsed and the insulator is repaired.

[0042] After the increasing M3 of the temperature, the temperature of the insulator is again reduced M4 to below the transition temperature, whereby the gel returns to its solid form. The repaired insulator 3 is thus once again in solid form, without any breakdown channels, cracks or other cavities in the gel 4.

[0043] After the reducing M4 of the temperature, the electrical device 1 is once again operated M5 at the operating temperature. Optionally, before the operating M5 of the electrical device with repaired and cooled M4 insulator 3, the electrical device, or the insulator thereof, may be tested at operating temperature and measurements may be made to determine whether the insulator is repaired or still suffering from the electrical breakdown.

[0044] The present disclosure has mainly been described above with reference to a few embodiments. However, as is readily appreciated by a person skilled in the art, other embodiments than the ones disclosed above are equally possible within the scope of the present disclosure, as defined by the appended claims.

Claims

1. A method of repairing an electrical insulator (3) of an electrical device (1) after electrical breakdown of said insulator, wherein the insulator comprises an oil-based thermo-reversible gel (4) comprising a thickener, the method comprising:

    operating (Mi) the electrical device (1) at an operating temperature below a transition temperature of the gel (4), at which the gel is in its solid form;
    during the operating (M1) of the device, determining (M2) electrical breakdown of the insulator (3);
    after the determining (M2), increasing (M3) the temperature of the insulator (3) to a repair temperature, which is above the transition temperature of the gel, whereby the gel (4) transitions to its liquid form;
    after the increasing (M3) of the temperature, reducing (M4) the temperature of the insulator to below the transition temperature, whereby the gel returns to its solid form; and
    after the reducing (M4) of the temperature, re-operating (M5) the electrical device (1) at an operating temperature below the transition temperature of the gel (4).

2. The method of claim 1, wherein the transition temperature is within the range of 60-110°C, e.g. within

the range of 60-90°C or 80-110°C.

3. The method of any preceding claim, wherein the operating temperature is up to 80°C, e.g. within the range of 50-80°C or 30-60°C.

4. The method of any preceding claim, wherein the repair temperature is maintained around the insulator (3) for at least 5 h, e.g. at least 8, 10 or 20 h, during the step of increasing (M3) the temperature of the insulator.

5. The method of any preceding claim, wherein the thickener comprises a styrenic block copolymer, e.g. a di- and/or a tri-block copolymer.

6. The method of any preceding claim, wherein the gel (4) is based on an oil selected among mineral oil, aromatic oil, ester oil and paraffinic oil, e.g. iso-paraffinic oil, or a mixture thereof.

7. The method of any preceding claim, wherein the gel (4) comprises dispersed particles of boron nitride.

8. The method of any preceding claim, wherein the electrical device (1) comprises a bushing, an instrument transformer, a power transformer, a capacitors or a cable ending.

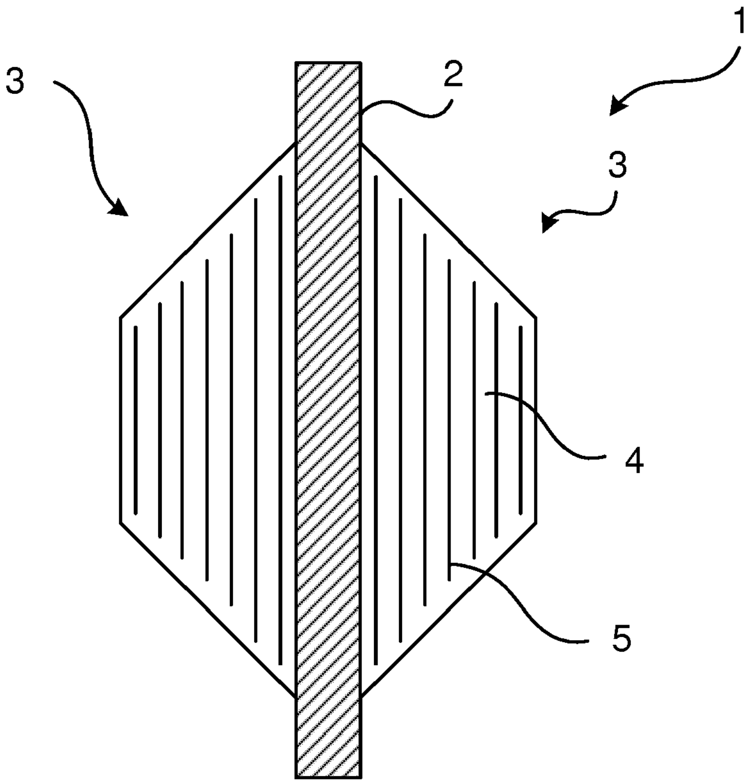

Fig. 1

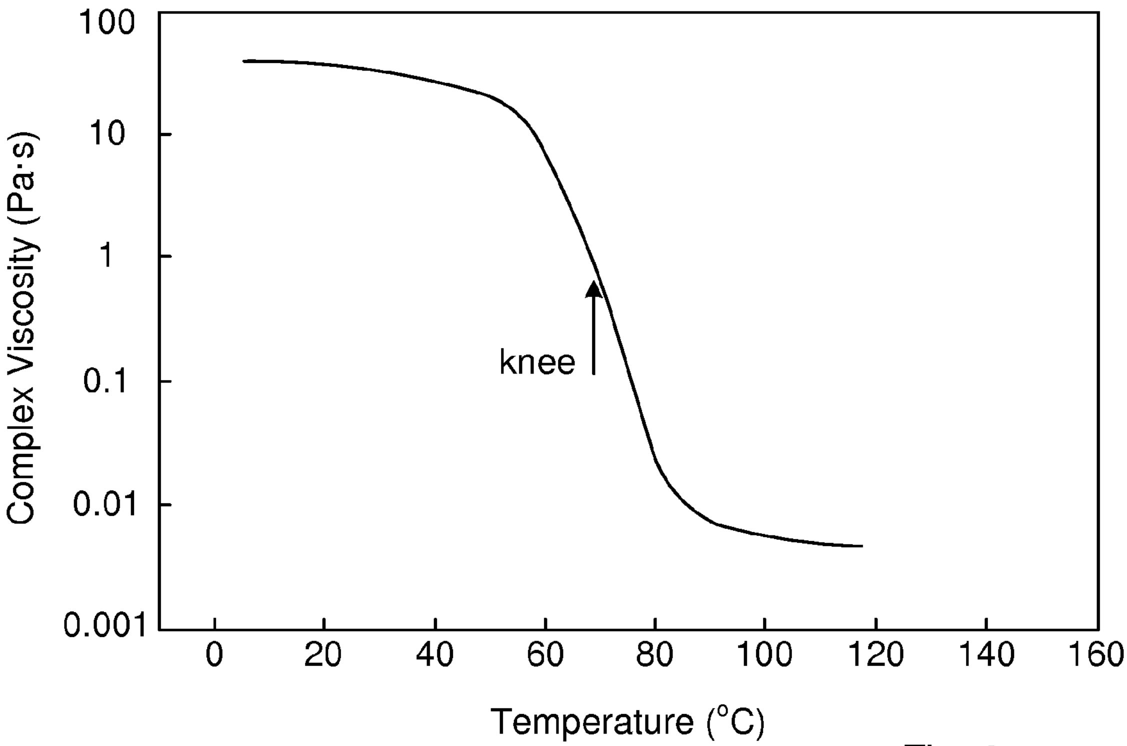
100
10
1
0.1
0.01
0.001
Complex Viscosity (Pa·s)
knee
0
20
40
60
80
100
120
140
160
Temperature (°C)

Fig. 2

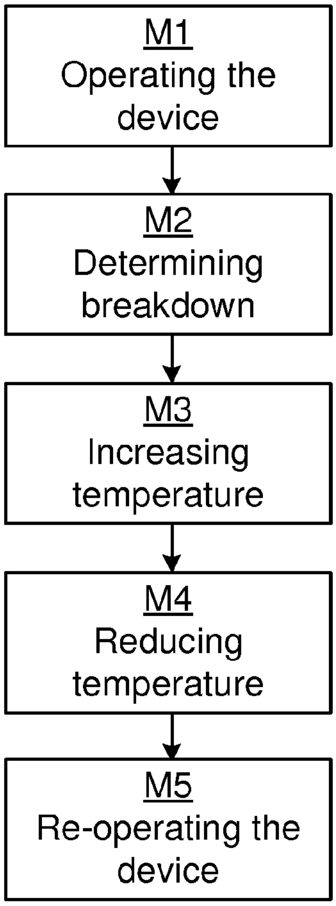
M1
Operating the device
M2
Determining breakdown
M3
Increasing temperature
M4
Reducing temperature
M5
Re-operating the device

Fig. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 18 16 2513

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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REFERENCES CITED IN THE DESCRIPTION

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