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(54) Title: INSULATION FLUID FILLING METHOD AND FILLING APPARATUS

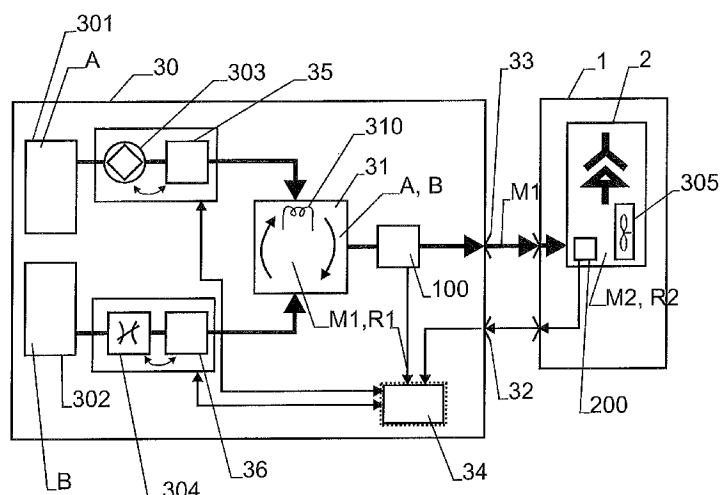


Fig. 1

(57) Abstract: A method and device for providing an insulation fluid (10) and for filling this insulation fluid (10) into a medium or high voltage switchgear (1) is provided. The method comprises method elements of mixing at least two fluid components (A, B) for yielding a first amount (M1) of insulation fluid (10), monitoring a first mixing ratio (R1) of this first amount (M1), and monitoring a second mixing ratio (R2) of a second amount (M2) of the insulation fluid (10) that is already in the electrical apparatus (1). The first mixing ratio (R1) is controlled such that no condensation of a fluid component (A, B) takes place. Furthermore, the first mixing ratio (R1) and the first amount (M1) of the insulation fluid are controlled using the second mixing ratio (R2), the second amount (M2), a desired target mixing ratio (R), and/or a target amount (M) of the insulation fluid.

Insulation fluid filling method and filling apparatus

Technical Field

The present invention relates to a method and
5 device for mixing fluid components to yield an insulation
fluid mixture and for filling this insulation fluid mix-
ture into an electrical apparatus, in particular into a
gas-insulated medium or high-voltage switchgear.

Introduction and Background Art

Dielectric insulation media in liquid and/or
gaseous states (i.e. fluids) are widely applied to insu-
late an electrically active part in a variety of electri-
cal apparatuses such as gas-insulated switchgear (GIS).
15 For example, the electrically active part in medium or
high voltage metal-encapsulated switchgear is arranged in
a gas-tight compartment which encloses an insulation gas
with a pressure of several bars, which electrically sepa-
rates the compartment of the apparatus from its electri-
20 cally active part. In other words, the insulation gas
does not allow the passage of electrical current from the
electrically active part to the compartment. A commonly
used dielectric insulation gas is sulfur hexafluoride
(SF₆), which exhibits excellent insulation and electric
25 arc extinguishing capabilities. However, SF₆ is a strong
contributor to the green-house effect and thus has a high
global warming potential. Therefore alternative insula-
tion fluids should be found.

Several alternative insulation fluids have
30 been identified. Some of these alternatives comprise mul-
ti-component fluid mixtures, i.e. they comprise more than
one molecular or atomic species. It is found that certain
properties of such insulation fluid mixtures are compul-
sory to the safe operation of the electrical apparatus.
35 As an example, the dielectric break-down strength of the
insulation fluid is strongly dependent on local concen-
tration ratios of the mixture fluid components and on to-

tal fluid pressure. In order to achieve and upkeep the mixture's insulating features and thus the safety and functionality of the electrical apparatus, the fluid components need to be carefully mixed and delivered to the electrical apparatus.

Niemeyer L., "Cigre Guide for SF6 gas mixtures", 1st international conference on SF6 and the Environment, November 2000 comments on suitable mixing procedures for multi-component insulation gas mixtures.

US 2011/0297149 A1 discloses a veterinary anesthesia monitor which establishes, maintains, and reports upon anesthesia gas mixtures.

EP 0 894 506 A2 relates to a medical anesthesia delivery system for providing flows of breathing and anesthesia gases to a patient. The anesthesia delivery system comprises a feedback and control circuit to analyze and regulate the mixing ratio of patient inhaled gases.

The disclosed methods and devices have the disadvantage, however, that they are not suitable for controlled filling of electrical apparatuses, in particular for delivering well-defined mixing ratios at pressures above atmospheric pressure.

Disclosure of the Invention

Hence it is a general objective of the present invention to provide an improved method and device for providing an insulation fluid mixture for an electrical apparatus and for filling this insulation fluid mixture into the electrical apparatus.

These objectives are achieved by the method and device of the independent claims.

Accordingly, a method for filling a first amount of an insulation fluid which comprises at least a first fluid component and a second fluid component into a compartment of a fluid-insulated electrical apparatus

(such as, e.g., gas-insulated medium or high voltage switchgear) comprises a method element of

- mixing the at least two fluid components which are to be comprised in a first amount of the insulation fluid. This is done at a first mixing ratio, i.e. at a desired mixing ratio for the first amount of the insulation fluid. Thus, the first amount of mixed insulation fluid is yielded.

The mixing-step as well as the other method elements in the method (see below) are carried out at a filling temperature T_{fill} , e.g. at ambient temperature, e.g. 20°C during commissioning of the electrical apparatus.

The method further comprises a method element of

- deriving the first mixing ratio of the first amount of the insulation fluid, i.e. an actual mixing ratio of the first amount of the insulation fluid that can deviate from a desired first mixing ratio during the mixing step. This is achieved by means of a first sensor, such as a gas chromatograph, an optical sensor, and/or a p-T-p-sensor (see below). Thus, information indicative of the actual first mixing ratio of the first amount of the insulation fluid is obtained.

Alternatively or in addition to deriving the first mixing ratio of the first amount of the insulation fluid, the method further comprises a method element of

- deriving a second mixing ratio of an (optional) second amount of the insulation fluid which is already present in the compartment of the electrical apparatus. This is achieved by means of a second sensor which can, e.g., be an integral part of the electrical apparatus or which can only be temporarily arranged in the compartment of the electrical apparatus. Thus, information indicative of the actual second mixing ratio of the second amount of the insulation fluid in the compartment of the electrical apparatus is obtained. In other

words, the mixing ratio of the insulation fluid that is already in the compartment of the electrical apparatus (i.e. the second mixing ratio of the second amount of the insulation fluid) is derived by means of the second sensor. Like the first sensor, also the second sensor can, e.g., comprise a gas chromatograph, an optical sensor, and/or a p-T-p-sensor (see below).

The method comprises a further method element of

10 - filling the first amount of the insulation fluid into the compartment of the electrical apparatus. There, this first amount of insulation fluid is actively (e.g. via a fan) or passively (e.g. via diffusion) mixed with the optional second amount of the insulation fluid that is already in the compartment (if any). Thus, the total amount of insulation fluid in the compartment of the electrical apparatus is increased while information indicative of the first and/or the second mixing ratio(s) prior to and/or after filling is available.

20 The first mixing ratio of the first amount of the insulation fluid is controlled such, or - in other words - the amount of the first component and the amount of the second component that are mixed to yield the first amount of the insulation fluid are controlled such, that condensation temperatures of the first and second fluid components in the first amount (i.e. in the insulation fluid that is to be filled into the compartment) are below the filling temperature T_{fill} . In other words, the first mixing ratio is controlled in a way that no condensation of one or more fluid components takes place during the mixing and filling of the insulation fluid into the electrical apparatus. Thus, it is ensured that during the filling method the insulation fluid is in a gaseous form and that no condensation which could alter the mixing ratios takes place.

35 The first mixing ratio of the first amount and the first amount of the insulation fluid itself (i.e.

the concentrations of the first and second fluid components as well as the total number of particles in the first amount) are furthermore controlled using the second mixing ratio and the second amount of the insulation fluid which is already in the compartment (if any). In other words, the first mixing ratio and the first amount of still-to-be filled insulation fluid is controlled depending on the second mixing ratio and the second amount of insulation fluid that is already in the compartment of the electrical apparatus. Alternatively or in addition, the first mixing ratio of the first amount and the first amount of the insulation fluid itself are controlled using a target mixing ratio and a target amount of insulation fluid in the compartment of the electrical apparatus. The terms "target mixing ratio" and "target amount" refer to a mixing ratio or an amount of insulation fluid, respectively, that is or are to be reached after completion of the filling process or at least at a later stage during the filling process, e.g. at the end of the commissioning procedure of the electrical apparatus. By controlling the first mixing ratio and the first amount using the second mixing ratio and the second amount and/or a target mixing ratio and a target amount, the compartment of the electrical apparatus can be more easily filled with the right amount (i.e. "target amount") of insulation fluid with the right mixing ratio (i.e. "target mixing ratio") for reliable operation of the electrical apparatus.

In an embodiment of the method, a filling pressure (which is, in other words, an equivalent to the "target amount" for a fixed volume of the compartment) of the insulation fluid in the compartment of the electrical apparatus after the above described filling step is above 1 bar, preferably above 2 bars, more preferably above 5 bars (measured at an insulation fluid temperature of 20°C, which can also be the filling temperature of the electrical apparatus of the electrical apparatus T_{fill}).

Thus, adequate amounts of insulation fluid and sufficient dielectric breakdown strength, e.g. for medium or high-voltage operation of the electrical apparatus, can be achieved in the compartment.

5 Preferably, the first and second fluid components are brought into (e.g. by a heater) - or, alternatively, it is ensured that they already are in - gaseous states, advantageously prior to carrying out the above described mixing step. Thus, the first mixing ratio can
10 more easily be controlled, e.g. by controlling and/or measuring flow rates of at least one fluid component, in particular of both fluid components.

 In another embodiment of the method, the first fluid component is in a liquid state at the filling
15 temperature (T_{fill}) and at a pressure of 1 bar and the second fluid component is in a gaseous state at the filling temperature (T_{fill}) and at a pressure between 5 bar and 200 bar. The first fluid component (A) is then brought into a gaseous state (e.g. by heating) and it is
20 ensured that the second fluid component is in a gaseous state and the fluid components are subsequently mixed at the filling temperature (T_{fill}) and at a pressure between 3 bar and 10 bar. This has the advantage that the first amount of the insulation fluid is yielded from a first
25 liquid (at the given conditions) component and from a second gaseous (at the given conditions) fluid component.

 In another embodiment, the method comprises a further method element of

 - homogenizing the first amount (which is to
30 be filled into the compartment) of the insulation fluid for reducing a mixture fluctuation and/or a density fluctuation in the first amount, and/or the method comprises a further method element of

 - homogenizing the second amount of the insulation fluid for reducing a mixture fluctuation and/or a
35 density fluctuation in the second amount of the insula-

tion fluid which is already in the compartment of the electrical apparatus.

This or these homogenization step(s) is or are preferably carried out prior to deriving the first and/or second mixture ratio(s) and lead(s) to a more homogeneous mixture and/or density of the fluid components in the respective amounts of insulation fluid and thus to a more reliable derivation of the first and/or second mixture ratio(s). Furthermore, due to the reduction of local mixture and/or density fluctuations, a more reliable filling and operation of the electrical apparatus is achieved or simplified.

In another embodiment, the method comprises a further method element of

- reducing the second amount of the insulation fluid in the compartment of the electrical apparatus 1, in particular prior to carrying out the step of filling the first amount of the insulation fluid into the compartment of the electrical apparatus. In other words, the (second) amount of insulation fluid in the compartment of the electrical apparatus is reduced or removed before the (first) amount of the insulation fluid is filled into the compartment. This is, e.g., very useful if during revision of the electrical apparatus the "old" insulation fluid needs to be fully or partially removed from the compartment (e.g. due to contamination) prior to filling the (first) amount of "freshly mixed" insulation fluid into the compartment.

Alternatively or additionally, the method comprises a further method element of

- reducing an amount of a filling gas in the compartment of the electrical apparatus, in particular prior to carrying out the step of filling the first amount of the insulation fluid into the compartment of the electrical apparatus. In other words, a filling gas, e.g. air or nitrogen, can at least partially be removed from the compartment before the first amount of insula-

tion fluid is filled into the compartment. This is, e.g., very useful, if during commissioning of the electrical apparatus ambient air that is present in the compartment needs to be fully or at least partially removed from the compartment prior to filling the first amount of "fresh" insulation fluid into the compartment.

This step has or these steps have the advantage that a "target amount" and/or "target mixing ratio" of insulation fluid can be as clean as possible and as precisely controlled as possible, which leads to a better insulation performance and thus to a more reliable operation of the electrical apparatus.

In another embodiment of the method, at least the method element of

- mixing the fluid components at the first mixing ratio, and
 - deriving
 - a) the first mixing ratio of the first amount of the insulation fluid and/or
 - b) the second mixing ratio of the second amount of the insulation fluid, and
 - filling the first amount of the insulation fluid into the compartment of the electrical apparatus
- are carried out repeatedly.

In other words, the above mentioned steps are repeated as long as the compartment of the electrical apparatus is not sufficiently filled with insulation fluid, or, in other words, as long as the "target mixing ratio" and/or the "target amount" of insulation fluid in the compartment is/are not yet reached. The term "repeatedly" as used herein refers to both a repeated execution of the above mentioned steps one-after-another with discernible start- and stop-points of all single steps as well as to a (timewise) continuous execution of at least some of the steps or method elements. As an example for such a repeated execution of the steps, during commissioning of the electrical apparatus, the mixing and filling steps

can be carried out continuously while the mixing-ratio-derivation-step(s) is or are carried out, e.g., once or twice every second. Then, if the second mixing ratio and/or the second amount of insulation fluid is or are
5 within a preset band around the target mixing ratio and/or target amount of the insulation fluid in the compartment (e.g. not differing by more than 5% from the target mixing ratio and/or from the target amount), the mixing and filling is stopped and the electrical apparatus is (at least as far as its fluid-insulation is concerned) ready for operation.
10

If the above mentioned steps are carried out repeatedly, the filling steps are preferably carried out against increasing second amounts of the insulation fluid
15 in the compartment (or, equivalently, against increasing insulation fluid pressures in the compartment). In other words, the total amount of insulation fluid in the compartment of the electrical apparatus increases over time due to the repeated filling of freshly mixed first
20 amounts of insulation fluid into the compartment. Thus, the target mixing ratio and/or the target amount of insulation fluid in the compartment can be reached using repeated (i.e. discernible and/or continuous) mixing and filling steps.

25 In another embodiment, the first sensor and/or the second sensor (each) comprises at least one of the group of

- a gas chromatograph for carrying out a gas chromatographic measurement on the first and/or second
30 amount of the insulation fluid. The term "gas chromatographic measurement" herein relates to an experimental quantification of a physical property (e.g. a retention time) of at least one fluid component of the insulation fluid comprising interactions between atoms or molecules
35 of the insulation fluid and a carrier fluid called the "mobile phase" and a fixed material called the "station-

ary phase". This stationary phase can, e.g., be located in a column of a gas chromatograph.

- An optical sensor for carrying out an optical measurement on the first and/or second amount of insulation fluid. The term "optical measurement" herein relates to an experimental quantification of a physical property of at least one fluid component of the insulation fluid comprising interactions between atoms or molecules of the insulation fluid and photons. Examples are

10 * optical absorption measurements by means of, e.g., a multi-pass spectroscope at, e.g., at least one wavelength between 0.2 μm and 20 μm or

 * fluorescence measurements, e.g., at at least one fluorescence excitation wavelength between 15 100 nm and 400 nm and/or at at least one fluorescence emission wavelength between 350 nm and 600 nm.

- A photoacoustic sensor for carrying out a photoacoustic measurement on the first and/or second amount of the insulation fluid. Such a photoacoustic measurement comprises optical excitation of at least one fluid component of the insulation fluid, e.g. in the wavelength range between 0.2 μm and 20 μm , followed by detection of the acoustic response of the insulation fluid using, e.g., a microphone. Alternatively or in addition, also acoustic sensors relying on other measurement principles can be used.

25 - A pressure (p) sensor, a temperature (T) sensor, and

 * a density (ρ) sensor,
30 * a speed of sound sensor,
 * a viscosity sensor, and/or
 * a thermal conductivity sensor.

More than three-parameter-sensor-systems can be used for error reduction and/or for more complex insulation fluid mixtures (e.g. comprising more than two fluid components). The respective mixing ratios of the first and/or second amount of the insulation fluid (or even the

35

concentrations of the first and second fluid components in the first and/or the second amounts) can, e.g., be derived using an equation of state (i.e. a "thermodynamic equation describing the state of matter under a given set of physical conditions" (from http://en.wikipedia.org/wiki/Equation_of_state as accessed on May 03, 2012) which is, e.g., selected from the group consisting of:

* the ideal gas law, i.e. $pV = nRT$ with p being an absolute pressure, V being a volume, n being a number of molecules (usually expressed in moles), R being the ideal gas constant, and T being an absolute temperature,

* the van-der-Waals equation of state, i.e. $(p + a/V_m^2)(V_m - b) = RT$ with V_m being a molar volume and a , b being substance-specific parameters for the respective insulation fluid component,

* the virial equation of state, i.e. $pV_m/(RT) = 1 + B(T)/V_m + C(T)/V_m^2 + D(T)/V_m^3 + \dots$ with $B(T)$, $C(T)$, $D(T)$, ... being temperature-dependent terms that correspond to interactions between molecules,

* the Beattie-Bridgeman equation of state, i.e. $p = R_u T / (V_m^2) (1 - c / (V_m T^3)) (V_m + B) - A / (V_m^2)$ with $A = A_0(1 - a/V_m)$, $B = B_0(1 - b/V_m)$, R_u being a gas constant in the form $R_u = 8.314 \text{ kPa m}^3/(\text{kmol K})$, V_m being a molar volume, and a , b , c , A_0 , and B_0 being substance-specific parameters for the respective insulation fluid component, and

* the Peng-Robinson equation of state, i.e. $p = RT / (V_m - e) - d(T) / (V_m(V_m + e) + e(V_m - e))$ with $d(T)$ and e being empirical parameters.

When an equation of state other than the ideal gas law is used, the behavior of a gas can be better predicted than with the ideal gas law alone and the prediction can be extended to liquids. This is possible by putting in terms to describe attractions and repulsions

between molecules as well as the molecular volume itself which leads to a reduction in the molar volume.

E.g., the document US 7 184 895 B2 gives details on how the fluid component concentration(s) is or
5 are derived using a pressure, a temperature, and a density measurement.

The term "concentration" herein defines

- a quantity (with units) which is indicative of an amount per volume unit, e.g. a particle number per
10 volume unit, moles per volume unit, or a number density, or

- a number (without units) which is indicative of a ratio such as a mole fraction, a pressure-normalized partial pressure, a volume fraction, a mass fraction, or
15 a density fraction.

The advantage of using a sensor or sensors as described above is that information indicative of the first and/or second mixing ratio(s) is easier to obtain. Specifically, the signals from the sensor(s) are used to
20 derive the actual first and/or second mixing ratio(s), and the desired first mixing ratio is controlled using this information. This simplifies the process of reaching the correct target mixing ratio as well as target amount of insulation fluid in the compartment of the electrical
25 apparatus.

In another embodiment, the method comprises a further method element of

- deriving a mass flow of at least one of the fluid components (or advantageously deriving mass flows
30 of all fluid components in the first amount) prior to or during the step of filling the first amount of the insulation fluid into the compartment of the electrical apparatus. This has the further advantage that information indicative of the total amount of the respective fluid
35 component that is filled into the compartment of the electrical apparatus is available. Thus, e.g., the mixing and/or filling process(es) can be stopped as soon as a

target amount of the respective fluid component in the compartment of the electrical apparatus is reached.

In another embodiment of the method, the first fluid component is selected from the group consisting of:

- sulfur hexafluoride,
- partially or fully fluorinated ethers, in particular hydrofluoroethers, hydrofluoro monoethers, hydrofluoro monoethers containing at least 3 carbon atoms, perfluoro monoethers, or perfluoro monoethers containing at least 4 carbon atoms,
- partially or fully fluorinated ketones, in particular hydrofluoro monoketones, perfluoro monoketones, perfluoro monoketones comprising at least 5 carbon atoms, or perfluoro monoketones comprising exactly 5 or 6 or 7 or 8 carbon atoms, and
- mixtures thereof.

The second fluid component B is selected from the group consisting of:

- nitrogen,
- oxygen,
- carbon dioxide,
- nitric oxide,
- nitrogen dioxide,
- nitrous oxide,
- argon,
- methanes, in particular partially or fully halogenated methanes, in particular tetrafluoromethane or trifluoriodomethane,
- air, in particular technical air or synthetic air, and
- mixtures thereof.

Thus, an improved insulation performance can be achieved for the insulation fluid of the electrical apparatus.

In further embodiments, the first fluid component is selected from the group consisting of:

- cyclic and/or aliphatic fluoropentanones, preferably cyclic and/or aliphatic perfluoropentanones, more preferably 1,1,1,3,4,4,4-heptafluoro-3-(tri-fluoromethyl)butan-2-one,

5 - cyclic and/or aliphatic fluoroheptanones, preferably cyclic and/or aliphatic perfluoroheptanones, more preferably 1,1,1,2,4,4,5,5,5-nonafluoro-4-(tri-fluoromethyl)pentan-3-one,

- cyclic and/or aliphatic fluoroheptanones, preferably cyclic and/or aliphatic perfluoroheptanones, 10 - sulfur hexafluoride, and - hydrofluoroethers.

Thus, an improved insulation performance can be achieved for the insulation fluid of the electrical 15 apparatus.

In another embodiment, the second fluid component consists of:

nitrogen and oxygen with relative partial pressures between $p(\text{N}_2)/(p(\text{O}_2)+p(\text{N}_2))=0.7$, $p(\text{O}_2)/(p(\text{O}_2)+p(\text{N}_2))=0.3$ and $p(\text{N}_2)/(p(\text{O}_2)+p(\text{N}_2))=0.95$, $p(\text{O}_2)/(p(\text{O}_2)+p(\text{N}_2))=0.05$ or

carbon dioxide and oxygen with relative partial pressures between $p(\text{CO}_2)/(p(\text{O}_2)+p(\text{CO}_2))=0.6$, $p(\text{O}_2)/(p(\text{O}_2)+p(\text{CO}_2))=0.4$ and $p(\text{CO}_2)/(p(\text{O}_2)+p(\text{CO}_2))=0.99$, $p(\text{O}_2)/(p(\text{O}_2)+p(\text{CO}_2))=0.01$, or

carbon dioxide and nitrogen with relative partial pressures between $p(\text{CO}_2)/(p(\text{N}_2)+p(\text{CO}_2))=0.1$, $p(\text{N}_2)/(p(\text{N}_2)+p(\text{CO}_2))=0.9$ and $p(\text{CO}_2)/(p(\text{N}_2)+p(\text{CO}_2))=0.9$, $p(\text{N}_2)/(p(\text{N}_2)+p(\text{CO}_2))=0.1$.

30 The first fluid component A comprises at least one of the group consisting of:

1,1,1,3,4,4,4-heptafluoro-3-(tri-fluoromethyl)butan-2-one with a partial pressure between 0.1 bar and 0.7 bar at a temperature of 20°C,

35 1,1,1,2,4,4,5,5,5-nonafluoro-4-(tri-fluoromethyl)pentan-3-one with a partial pressure between 0.01 bar and 0.3 bar at a temperature of 20°C,

sulfur hexafluoride with a partial pressure between 0.1 bar and 2 bar at a temperature of 20°C, and hydrofluoroethers with a partial pressure between 0.2 bar and 1 bar at a temperature of 20°C.

5 Thus, an improved insulation performance can be achieved for the insulation fluid of the electrical apparatus.

In another embodiment, the second fluid component comprises

10 nitrogen and oxygen with relative partial pressures between $p(N_2)/(p(O_2)+p(N_2))=0.75$, $p(O_2)/(p(O_2)+p(N_2))=0.25$ and $p(N_2)/(p(O_2)+p(N_2))=0.90$, $p(O_2)/(p(O_2)+p(N_2))=0.10$ and

15 wherein the first fluid component (A) comprises 1,1,1,3,4,4,4-heptafluoro-3-(tri-fluoromethyl)butan-2-one with a partial pressure between 0.25 bar and 0.5 bar and/or the fluid component 1,1,1,2,4,4,5,5,5-nona-fluoro-4-(tri-fluoromethyl)pentan-3-one with a partial pressure between 0.02 bar and 0.3 bar at a temperature of 20°C.

20 Thus, an improved insulation performance can be achieved for the insulation fluid of the electrical apparatus.

In another embodiment, the method comprises a further method element of

25 - deriving a first concentration of the first fluid component of the second amount of the insulation fluid in the compartment of the electrical apparatus.

The method comprises a further method element of

30 - deriving a second concentration of the second fluid component of the second amount of the insulation fluid in the compartment of the electrical apparatus.

35 This information can, e.g., be derived using a sensor arrangement as discussed above in the electrical apparatus and/or using integrated mass flow measurements

of the filled amounts of the first fluid components. Thus, the fluid component concentrations of the insulation fluid in the compartment of the electrical apparatus are derivable.

5 In embodiments, the method further comprises a method element of deriving a dielectric break-down strength E_{bd} of a or the second amount of the insulation fluid in the compartment of the electrical apparatus. This is achieved using a or the first concentration of
10 the first fluid component of the insulation fluid and using a or the second concentration of the second fluid component of the insulation fluid, and, e.g., using the following equation

$$15 \quad E_{bd} = S(c_A, c_B) \sum_{i=A,B} c_i E_{crit,i}$$

Here, $E_{crit,A}$ and $E_{crit,B}$ are fluid component specific critical field strengths of the first fluid component A and the second fluid component B; c_A and c_B are the first and second concentrations of the first and second fluid components A and B; $S(c_A, c_B)$ is a synergy parameter; and i is an index running over the fluid components A and B.

Then, the dielectric break-down strength E_{bd} of the insulation fluid in the compartment of the electrical apparatus is derivable and it can be compared to a
25 target dielectric breakdown strength. As soon as this target dielectric breakdown strength is reached, the mixing and/or filling can be stopped and the electrical apparatus is (at least as far as its fluid-insulation is
30 concerned) ready for operation.

In other embodiments, the method comprises a further method element of

- deriving an operating state of the electrical apparatus using a or the first concentration of the
35 first fluid component and using a or the second concentration of the second fluid component in the second

amount of the insulation fluid in the compartment of the electrical apparatus.

Furthermore or in addition, the method comprising a further method element of

- 5 - deriving an operating state of the electrical apparatus using a or the dielectric break-down strength E_{bd} of the second amount of the insulation fluid in the compartment of the electrical apparatus.

This operating state can be selected from a group of possible operating states consisting of:

- 10 - normal, i.e. undisturbed, operation of the electrical apparatus,
- underfilling of the compartment, i.e. an insufficient (second) amount of insulation fluid in the compartment of the electrical apparatus,
- 15 - overfilling of the compartment, i.e. a superfluous (second) amount of insulation fluid in the compartment of the electrical apparatus,
- uniform leakage of the second amount of the insulation fluid, i.e. fluid component-independent loss of insulation fluid from the compartment of the electrical apparatus,
- 20 - preferential leakage of one fluid component (A or B) from the second amount of the insulation fluid, i.e. increased loss of one fluid component compared to the other fluid component, thus leading to a change of the second mixing ratio of the insulation fluid in the compartment of the electrical apparatus,
- 25 - condensation or preferential condensation of one fluid component from the second amount of the insulation fluid, e.g. a state transition from gaseous to liquid state or vice versa of only one or at least preferentially one fluid component (A or B) of the second amount of the insulation fluid in the compartment of the electrical apparatus,
- 30 - adsorption or preferential adsorption of one fluid component (A or B) of the second amount of the
- 35

insulation fluid, e.g., on a component of the electrical apparatus, e.g., on an inner surface of the compartment of the electrical apparatus,

- chemical process or preferential chemical process of one or pertinent to one fluid component (A or B) of the second amount of the insulation fluid,

- appearance of at least one new fluid component in the second amount of the insulation fluid, e.g. due to arcing, partial discharges, evaporation, light, high temperature, or any other chemical process or stemming from any other source, in particular wherein the new fluid component is a contaminant, i.e. an undesired substance in the insulation fluid, and

- decomposition or preferential decomposition of at least one fluid component (A and/or B) of the second amount of the insulation fluid, e.g. due to arcing, partial discharges, light, high temperature, and/or reactions of at least one of the fluid components (A and/or B).

Thus, a plurality of different operating scenarios for the electrical apparatus can be distinguished and, e.g., troubleshooting in the case of malfunctions is enabled or simplified. An identification of the operating state is possible by, e.g., comparing the first and second fluid component concentrations in the second amount of the insulation fluid to already filled first amounts of the insulation fluid as, e.g., known from integrated mass flow measurements.

Other optional possible operating states can e.g. be:

- intermolecular reactions between molecules of the at least two fluid components (A, B), and

- removal of at least one of the at least two fluid components (A, B), e.g., due to adsorption onto surfaces.

Thus, even more operating scenarios for the electrical apparatus can be distinguished and, e.g.,

troubleshooting in the case of malfunctions is improved or simplified further.

It should be noted that it is also possible to alternatively or additionally derive fluid component concentrations and/or a dielectric breakdown strength of the first amount of the insulation fluid that is to be filled into the compartment of the electrical apparatus and to use these values in the derivation of the operating state of the electrical apparatus.

As another aspect of the invention, an insulation fluid filler (i.e. a filling device) for filling at least a first amount of an insulation fluid into a compartment of a fluid-insulated electrical apparatus (in particular gas-insulated medium or high voltage switchgear) as described above comprises

- a mixer for mixing at least two fluid components at a first mixing ratio. This mixer can be an active (e.g. comprising a fan) or a passive (e.g. relying on diffusion) mixer.

Furthermore, the insulation fluid filler comprises

- a first sensor for deriving this first mixing ratio of the first amount of the insulation fluid that is to be filled into the electrical apparatus.

Alternatively or in addition, the insulation fluid filler comprises

- an interface for receiving a sensor signal indicative of a second mixing ratio of a second amount of the insulation fluid that is already in the compartment of the electrical apparatus. As an example, the electrical apparatus comprises a second sensor for deriving this second mixing ratio of the second amount of insulation fluid and transmits a sensor signal indicative of this second mixing ratio via the interface to the insulation fluid filler.

Furthermore, the insulation fluid filler comprises

- a fluid connector for establishing connection for insulation fluid between the insulation fluid filler and the electrical apparatus and for transferring the first (newly mixed) amount of the insulation fluid from the insulation fluid filler to the electrical apparatus.

Additionally, the insulation fluid filler comprises

- an analysis and control unit which is adapted and structured to carry out the method elements of a method as described above.

In an embodiment, the analysis and control unit of the insulation fluid filler comprises a computer program element comprising computer program code means for, when executed by a processing unit of the insulation fluid filler, implementing a method as described above.

The described embodiments and/or features similarly pertain to the apparatuses and the methods. Synergetic effects may arise from different combinations of these embodiments and/or features, although they might not be described in detail.

Brief Description of the Drawings

The invention and its embodiments will be more fully appreciated by reference to the following detailed description of presently preferred but nonetheless illustrative embodiments in accordance with the present invention when taken in conjunction with the accompanying drawings.

Fig. 1 shows an insulation fluid filling apparatus or filler 30 according to the invention as well an electrical apparatus 1;

Fig. 2 shows a schematic of an optical fluorescence sensor;

Fig. 3 shows a schematic of an optical absorbance sensor 100, 200;

Fig. 4 shows a schematic of a gas chromatograph 100, 200 comprising two columns and a mass spectrometer behind one column;

Fig. 5 shows a chromatogram illustrating the separation of insulation fluid components "N₂/O₂" and "C5" and "C6";

Fig. 6 shows two chromatograms illustrating loss of a specific fluid component "gas 4";

Fig. 7 shows two chromatograms illustrating detection of a contaminant;

Fig. 8 shows an absorption diagram illustrating characteristic optical absorbance signatures of insulation fluid components "C5" and "C6" in the infrared region;

Fig. 9 shows absorption diagrams illustrating the detection of a contaminant "HF" of the insulation fluid;

Fig. 10 shows an absorption diagram in the near UV range for "acetone", "C5", and "C6";

Fig. 11 shows an infrared absorption spectrum illustrating characteristic optical absorbance signatures of an insulation fluid component "C5";

Fig. 12 shows infrared absorption spectra illustrating the characteristic optical absorbance signatures of the insulation fluid component "C5" of Fig. 11 as well as characteristic optical absorbance signatures of a contaminant "CF₄";

Fig. 13 shows infrared absorption spectra illustrating the characteristic optical absorbance signatures of the insulation fluid component "C5" of Fig. 11 as well as characteristic optical absorbance signatures of a contaminant hexafluoropropene "CF₃CF=CF₂";

Fig. 14 shows infrared absorption spectra illustrating the characteristic optical absorbance signatures of the insulation fluid component "C5" of Fig. 11 as well as characteristic optical absorbance signatures of a contaminant heptafluoropropane "CF₃CFHCF₃";

Fig. 15 shows a schematic of an optical absorbance measurement comprising a spectrometer;

Fig. 16 shows an "optical absorption" vs. "C5 pressure" diagram as recorded by an optical setup of
5 Fig. 15;

Fig. 17 shows a schematic of an optical absorbance measurement comprising a non-dispersive photodetector and a band-pass filter;

Fig. 18 shows a "transmitted intensity" vs. "C5 pressure" diagram as recorded by an optical setup of
10 Fig. 17;

Fig. 19 illustrates the dependence of UV absorption of the insulation fluid component "C5" on different insulation fluid mixture ratios and/or pressures;

Fig. 20 shows a photoionization detector 100,
15 200; and

Fig. 21 shows a pTp detector 100, 200 in bypass configuration.

20

Modes for Carrying Out the Invention

Description of the Figures:

Fig. 1 shows a schematic of an insulation fluid
25 filler or filling apparatus 30 according to the invention. The insulation fluid filler 30 operates at a filling temperature T_{fill} which corresponds to the ambient temperature of, e.g., 20°C. The insulation fluid filler 30 comprises two fluid component reservoirs 301 and 302
30 for holding fluid components A and B, respectively.

Here, fluid component A comprises a perfluoroketone C5 which is a liquid at room temperature and at a pressure of 1 bar. A pump 303 conveys a stream (upper bold arrow) of liquid fluid component A to a mixer 31.
35 The flux of the liquid fluid component A is monitored and controlled by a mass flow meter and regulator 35. In other words, the mass flow meter and regulator 35 measures

and regulates the mass flux of fluid component A that enters the mixer 31. Information about the mass flux is transmitted to an analysis and control unit 34 of the insulation fluid filler 30 and mass flux regulation commands are received from this analysis and control unit 34. With the mass flux information, also a closed-loop operation of the pump 303, e.g. a variable pump speed controlled by the mass flow meter and regulator 35 that maintains a desired mass flux, is possible (indicated by the upper curved arrow in Fig. 1).

Fluid component B consists of a pressurized gas mixture consisting of, e.g., 95% carbon dioxide and 5% oxygen at a total overpressure of 15 bars and is gaseous at ambient temperature. Due to the overpressure and a pressure gradient, a flow of gaseous fluid component B (lower bold arrow) automatically reaches the mixer 31 of the insulation fluid filler 30 after passing through a pressure regulator 304 which downregulates the fluid component pressure to 10 bars and through a mass flow meter and regulator 36 which measures and regulates the mass flux of fluid component B that enters the mixer 31. This information is again transmitted to the analysis and control unit 34 and regulation control commands are received from the analysis and control unit 34 of the insulation fluid filler 30. As discussed above, closed loop operation of the pressure regulator 304 and the mass flow meter and regulator 36 is possible (lower curved arrow).

In the mixer 31 the liquid fluid component A is vaporized by a heater 310 and mixed with the gaseous fluid component B in a turbulent jet mixing zone (curved arrows in 31). Thus, the first amount M1 of insulation fluid 10 is yielded. Due to the controlled amounts of fluid components A and B that are mixed in the mixer 31, the first amount of the insulation fluid 10 has a first mixing ratio R1, or - equivalently - the first fluid component A has a first concentration c_A and the second fluid component B has a second concentration c_B .

It should be noted in this respect that the mixing and thus yielding of the first amount M1, measuring of mixing ratios, and filling of the first amount M1 of the insulation fluid 10 can be continuous processes (see
5 above).

Then, the first amount M1 of the insulation fluid 10 is transferred to the compartment 2 of the electrical apparatus 1 via a fluid connector 33 of the insulation fluid filler 30 and via suitable tubing (bold arrows). Before the first amount M1 of the insulation fluid
10 10 leaves the insulation fluid filler 30, however, the first mixing ratio R1 and/or the first amount M1 is derived using a first sensor 100, which is an optical fluorescence sensor as described in Fig. 2 below and/or a
15 mass flow sensor. Alternatively, an optical absorbance sensor from Fig. 3, a photoionization sensor from Fig. 20, a pTp sensor from Fig. 21, or any other suitable sensor or sensor combination can be used. The information indicative of the first mixing ratio R1 from the first
20 sensor 100 is transmitted to the analysis and control unit 34 and compared to the mixing ratio as determined by the mass fluxes of the single fluid components A and B (see above). Thus, the detection of failure states such as condensation is simplified.

Furthermore, before filling of the first amount
25 M1 into the compartment 2, the second mixing ratio R2 and the second amount M2 of the insulation fluid 10 which is already in the compartment 2 of the electrical apparatus are also measured by a second sensor 200 (e.g. comprising
30 any of the sensors mentioned above, or combinations thereof) and transmitted to the analysis and control unit 34 via an interface 32.

As soon as the first amount M1 reaches the compartment 2 of the electrical apparatus 1, the transferred
35 first amount M1 of the insulation fluid 10 with the first mixing ratio R1 is then mixed with the already present second amount M2 of the insulation fluid 10 which has

(before mixing) a second mixing ratio R2 (see above). This mixing is accelerated by a circulator 305. The circulator 305 homogenizes the density and/or the mixture of the insulation fluid components A and B.

5 By filling the first amount M1 into the compartment 2, the total amount of insulation fluid 10 in the compartment 2 of the electrical apparatus is increased.

During all these steps, the first mixing ratio R1 of the first amount M1 of the insulation fluid 10 (that has been transferred into the compartment 2) is controlled such that condensation temperatures of the fluid components A and B of the insulation fluid 10 are below the filling temperature T_{fill} . In other words, it is ensured that no condensation takes place.

15 The first mixing ratio R1 and the first amount M1 of the insulation fluid 10 that is transferred into the compartment 2 are further controlled using

* the second mixing ratio R2 and the second amount M2 of insulation fluid 10 in the compartment 2 (before filling) and using

20 * a target mixing ratio R (e.g. 5.5 % perfluoroketone C5, 94.5 % CO₂-O₂-mixture) and a target amount M (e.g. equivalent to 7.7 bar at 20°C) of insulation fluid 10 which are to be reached after completion of the filling process.

25 In other words, knowing the second mixing ratio R2 and the second amount M2 of insulation fluid 10 in the compartment 2, the analysis and control unit 34 derives how much (i.e. the first amount M1) insulation fluid 10 at which mixture (i.e. the first mixing ratio R1) needs to be filled into the compartment 2 so that the target amount M at target mixing ratio R are reached.

35 Furthermore, after filling another measurement of R2 and M2 are taken and this information from the second sensor 200 enables the analysis and control unit 34 to derive concentrations c_A and c_B of the first and second fluid components A and B in the compartment 2. Us-

ing these data, the analysis and control unit 34 can then optionally in addition derive an operating state 0 of the electrical apparatus 1. Specifically, dielectric breakdown strength E_{bd} of the insulation fluid 10 is derived
 5 according to

$$E_{bd} = S(c_A, c_B) \sum_{i=A,B} c_i E_{crit,i}$$

with $E_{crit,A}$ and $E_{crit,B}$ being known and preset fluid-component-specific critical field strengths of the fluid components A and B. $S(c_A, c_B)$ is a known and preset synergy parameter and i is an index running over the fluid components A and B. From this dielectric breakdown strength E_{bd} of the insulation fluid 10, the operating state 0 is derived which is indicative of the availability of the electrical apparatus for normal operation,
 15 e.g. current conduction or high-voltage switching.

With this information available, the insulation fluid filler 30 can stop the filling procedure as soon as a threshold of the dielectric breakdown strength E_{bd} is reached or exceeded.
 20

Fig. 2 shows a schematic of an optical fluorescence sensor 100, 200 as it can be used in the insulation fluid filler 30 of Fig. 1 or in the electrical apparatus 1. Here, fluorescence excitation light from a light source 23 (e.g. a laser, LED, VCSEL) is collimated by a lens 24 and passes a dichroic beam splitter 28. It then passes through the wall of a glass tube whose inner volume is filled with to-be-measured insulation fluid 10, either from a by-pass-arrangement at an insulation fluid tubing or from an extraction of a small amount (e.g. 1 ml at 1 bar at room temperature) of insulation fluid 10. This glass tube forms the measurement cell 21 of the optical sensor 100. In another application, the measurement cell 21 of the optical sensor 200 can be formed by the compartment 2 of the electrical apparatus 1 itself, i.e. fluorescence is then measured inside the compartment 2.
 35 The fluorescence excitation light then excites molecules

of the insulation fluid 10 and resulting fluorescence emission light is in part travelling back towards the beam splitter 28. To increase light collection efficiency, a mirror 27 is arranged on a side of the glass tube opposing the beam splitter 28. Fluorescence emission photons are then deflected by the dichroic beam splitter 28, pass an emission filter 26 (which blocks leftover excitation light), and are focused onto a detector 25 (e.g. an avalanche photodiode or a photomultiplier tube) by a collection lens 24. The electrical fluorescence signal (indicative of c_A and c_B) from the detector 25 is then read out, optionally preprocessed (not shown), and transmitted to the analysis and control unit 34 of the insulation fluid filler 30 for further processing. It should be noted that different light sources and optical setups are possible, e.g. monochromatic light at one or more wavelengths (e.g. at 305 nm) from one or more laser(s) 23, narrow spectrum light from a narrow band LED light source 23 (e.g. in the near UV range), or polychromatic or white light (optionally with a monochromator such as a grating) from a conventional light source 23. It is also possible to use different optical sensors 100, 200 for the different fluid components A and B.

Fig. 3 shows a schematic of an optical absorbance sensor 100, 200 as it can be used in the insulation fluid filler 30 from Fig. 1 or in the electrical apparatus 1. Here, light is monochromized inside a light source 23 by a grating (only schematically shown) and split into two beams by a e.g. 50:50 beam splitter 28. One light beam is guided through a reference cell 21a with a known absorbance per wavelength. The other light beam is guided through a measurement cell 21 of the optical sensor which comprises the insulation fluid 10 which is to be measured optically. Again, bypass configurations (arrows) or extractions of small amounts of insulation fluid 10 (not shown) are possible. After traveling through the measurement cell 21 or the reference cell

21a, respectively, both light beams are propagated through band-pass filters 29 and focused onto photodetectors 25 (e.g. avalanche photodiodes) by lenses 24. By tuning the wavelength from the light source, an absorbance spectrum of the insulation fluid 10 over wavelength which is indicative of the fluid component concentrations c_A and c_B (or the mixing ratio) is measured. As discussed above with regard to the fluorescence optical sensor 100, 200, it should again be noted that different light sources and optical setups are possible as it is obvious to the person skilled in the art.

Advantages of using an optical sensor 100, 200 for deriving the fluid component concentrations c_A , c_B , (or the mixing ratios of the insulation fluid 10) are:

- (i) high specificity to individual fluid components,
- (ii) high sensitivity,
- (iii) broad applicability to any insulation fluid mixture comprising optical absorption or fluorescence, and
- (iv) nonextractive measurement principle, i.e. no insulation fluid needs to be removed.

Fig. 4 shows a schematic of a gas chromatograph 100, 200 as it can be used in the insulation fluid filler 30 from Fig. 1 or in the electrical apparatus 1. The gas chromatograph 100, 200 comprises a carrier gas reservoir 331 and a sample injector 332 which accepts a small amount (e.g. 0.5 ml at 1 bar at 20°C) of the insulation fluid 10 from the first or the second amount of the insulation fluid 10. This insulation fluid 10 is then injected into the flowing carrier gas and propagated through two columns 333 onto detectors 334 (e.g. thermal conductivity detector, flame ionization detector, or electron capture detector, electron impact ionization detector). Due to different retention times of the fluid components A and B with a stationary phase in the columns, the concentrations values c_A and c_B (or the mixing ratio) can be measured. For example, the column Fluorocol from the company Supelco (Sigma-Aldrich) can separate a mixture of N_2/O_2 and C_5/C_6 . A mass spectrometer 335 is arranged be-

hind one column 333 for carrying out an additional mass spectrometric measurement for detecting and/or discriminating contaminants (i.e. undesired substances) in the insulation fluid 10.

5 Advantages of using a gas chromatographic measurement for deriving the fluid component concentrations c_A and c_B (or the mixing ratios of the insulation fluid 10) are: (i) good separation and quantification capability to individual fluid components, (ii) very good sensitivity, and (iii) the ability to diagnose unknown contaminants, e.g. by optionally using an additional mass spectrometer (see below).

15 Fig. 5 shows a chromatogram (i.e. a chromatograph detector signal as a function of retention time in the column) illustrating the separation of insulation fluid components "N₂/O₂" (technical air) and "C5" and "C6", which all appear as single separate peaks in the chromatogram. A Fluorocol column from the manufacturer Supelco can, e.g., be used for separation.

20 Fig. 6 shows two chromatograms illustrating electrical stress-induced loss of a specific fluid component (gas 4, peak drops, see arrow and dotted lines). An FC column can, e.g., be used for such a measurement.

25 Fig. 7 shows two chromatograms illustrating detection of a contaminant of the insulation fluid 10. An additional peak (arrow, dotted circle) appears after a fresh insulation gas mixture (fresh gas mixture) has undergone electrical stress (aged gas mixture). An FC column can, e.g., be used for such a measurement.

30 Fig. 8 shows an infrared absorption spectrum illustrating characteristic signatures of insulation fluid components C5 and C6 in the infrared region. The use of infrared spectroscopy offers an easy, specific, and accurate method for the determination (type and concentration) and monitoring of the fluid components that make up the insulation fluid 10. Many molecules, such as e.g. C5 (i.e. C5-fluoroketone) and C6 (i.e. C6-fluoroketone) show

35

characteristic spectral signatures (spectral fingerprint) in the infrared region which are, e.g., due to vibrational excitation. Specifically, measurements of the bands labeled C5-signature and C6-signature in the spectrum of the insulation fluid unambiguously indicate the presence and allow the concentration determination of C5 and/or C6, respectively. Note that the spectrum in the region 1200cm^{-1} to 1350 cm^{-1} is partially saturated.

Fig. 9 shows absorption diagrams illustrating the detection of a contaminant "HF" in the insulation fluid 10. Specifically, after electrical stress induced aging of an insulation fluid component "C5", clear absorption signatures of the contaminant "HF" can be seen in the spectrum. An HF reference spectrum is given for comparison. Using calibrated HF spectra, the concentration of the contaminant HF can also be derived. Analogous procedures exist for other contaminants.

Fig. 10 shows an absorption diagram in the UV range for acetone, C5, and C6 together with reference data for acetone.

Fig. 11 shows an infrared absorption spectrum illustrating characteristic optical absorption signatures of an insulation fluid component "C5". It is found that the insulation fluid component "C5" shows absorption peaks that do not overlap with spectral signatures of contaminants (indicated by, e.g., the arrow, see below). Therefore, by selecting such an appropriate spectral signature, the insulation fluid component "C5" can be unambiguously monitored without cross-sensitivity to contaminants.

Fig. 12 shows infrared absorption spectra illustrating the characteristic optical absorbance signatures of the insulation fluid component "C5" of Fig. 11 as well as characteristic optical absorbance signatures of a contaminant "CF₄" (as indicated by the arrow). Because these peaks do not overlap, they allow an unambiguous detection of the contaminant "CF₄", even in the presence of "C5".

Fig. 13 shows infrared absorption spectra illustrating the characteristic optical absorbance signatures of the insulation fluid component "C5" of Fig. 11 as well as characteristic optical absorbance signatures of a contaminant hexafluoropropene " $\text{CF}_3\text{CF}=\text{CF}_2$ " (as indicated by the arrows). Similar to the situation in Fig. 12, these signatures allow an unambiguous detection of the contaminant " $\text{CF}_3\text{CF}=\text{CF}_2$ ", even in the presence of "C5".

Fig. 14 shows infrared absorption spectra illustrating the characteristic optical absorbance signatures of the insulation fluid component "C5" of Fig. 11 as well as characteristic optical absorbance signatures of a contaminant heptafluoropropane " $\text{CF}_3\text{CFHCF}_3$ ". Similar to the situation in Figs. 12 and 13, these signatures allow an unambiguous detection of the contaminant heptafluoropropane " $\text{CF}_3\text{CFHCF}_3$ ", even in the presence of "C5".

Fig. 15 shows a schematic of an optical absorbance measurement comprising a spectrometer, i.e. a wavelength-discriminating or dispersive photodetector 25. Light from a light source 23 (e.g. a deuterium light source) is propagated through a measurement cell 21 comprising the insulation fluid 10. Then, a part of the light that has not been absorbed in the measurement cell 21 is detected by photodetector 25.

Fig. 16 shows an "optical absorption" vs. "C5 pressure" diagram as recorded by an optical setup of Fig. 15. In other words, absorption A in arbitrary units is plotted versus pressure p in mbar of pure insulation fluid component C5. The graph shows measured data (diamonds) together with a linear fit line (slope $a = 0.009872$, offset $A_{\text{offset}} = -0.019615$) as well as relative errors of measured values compared to the fit. Each data point corresponds to the area of the absorption peak for the respective "C5" concentration. The inset shows a typical absorption spectrum (i.e. wavelength in nm on x-axis, wavelength-dependent absorption in arbitrary units a.u. on y-axis, here for a partial pressure of C5-

perfluoroketone of e.g. $p(C5) = 91.5$ mbar) of insulation fluid component "C5" where the hatched region ($240 \text{ nm} < \lambda < 350 \text{ nm}$) represents the integration area which is used to measure the (integral) absorption A . The relative error $dA/A \leq \pm 2\%$ demonstrates that concentration determination of insulation fluid component "C5" is possible with high sensitivity and high precision, using simple calibration methods. The used equipment comprises: Light source 22: Deuterium light source, DT-MINI-2-GS, Ocean Optics. Gas cell 21: Stainless steel cell (with optical path length 47cm) "Expando" from Solvias. Fiber-optic cables 23: length 0.5 m, core diameter 600 μm , UV-0.5m/1204191 from Solvias. Detector 25: High-resolution spectrometer, HR4000 from Ocean Optics.

Fig. 17 shows a schematic of an optical absorbance measurement comprising a non-dispersive photodetector 25 and a band-pass filter 29. Light from a light source 23 (e.g. a deuterium light source) is propagated through a measurement cell 21 comprising the insulation fluid 10. Then, a part of the light that has not been absorbed in the measurement cell 21 propagates through a band-pass filter 29 and is detected in a non-wavelength-discriminating-fashion by photodetector 25.

Fig. 18 shows a "transmitted intensity" vs. "C5 pressure" diagram as recorded by an optical setup of fig. 17. In other words, transmitted intensity I in μW is plotted versus pressure p in mbar of pure insulation fluid component C5. The graph shows measured data (diamonds) together with exponential fit (line, Lambert-Beer law; with offset intensity $I_{\text{offset}} = 21.9 \mu\text{W}$, intensity coefficient $I_0 = I_0 = 35.8 \mu\text{W}$, and exponential coefficient $\epsilon = 0.0032 \text{ l/mbar}$) and relative error dI/I of measurement I compared to fit. Each data point corresponds to the total integrated intensity I measured by the silicon photodetector 25. Most of the light of the Deuterium light source which has a larger wavelength than the insulation fluid components' absorption peaks is blocked by a filter

(the light which is not blocked contributes to the offset I_{offset}). The relative error $dI/I \leq \pm 1\%$ demonstrates that concentration of insulation fluid component "C5" can be determined with high sensitivity and high precision.

5 The used equipment comprises: Light source 22: Deuterium light source, DT-MINI-2-GS, Ocean Optics. Gas cell 21: Stainless steel cell (with optical path length 47cm) «Expando» from Solvias. Fiber-optic cables 23: length 0.5 m, core diameter 600 μm , UV-0.5m/1204191 from
10 Solvias. Filter 29: UG-11 from Schott. Detector 25: Si Photodiode, UV-818 from Newport.

Fig. 19 illustrates the dependence of UV absorption of the insulation fluid component "C5" on insulation fluid mixtures and/or on insulation fluid pressure. In
15 other words, the absorption of pure insulation fluid component "C5" in gaseous form and of two different insulation fluid mixtures consisting of insulation fluid component "C5" and insulation fluid component of, e.g., "synthetic air" with different mixture ratios and total pressures is acquired with the optical setup of Fig. 19. The
20 absolute amount of insulation fluid component "C5" for all 3 samples (i.e. 3 graphs, only two are distinguishable here) is constant: $p(\text{C5}) = 91.5 \text{ mbar}$. The amount of synthetic air differs between 0 and 5775 mbar. The graph
25 illustrates that absorption values for all 3 insulation fluid mixtures do not or not significantly deviate for high or low pressures when synthetic air is added to the insulation fluid component "C5". This shows that a concentration of an insulation fluid component "C5" using a
30 C5 UV-absorption peak can be determined independently from the admixture of synthetic air. No effect is observed even up to a total insulation fluid pressure of $p_{\text{tot}} = 8.9 \text{ bar}$ (data not shown).

35 The used equipment comprises: Light source 22: Deuterium light source, DT-MINI-2-GS, Ocean Optics. Gas cell 21: Stainless steel cell (with optical path length 47cm) "Expando" from Solvias. Fiber-optic cables 23:

length 0.5 m, core diameter 600 μm , UV-0.5m/1204191 from Solvias. Detector 25: High-resolution spectrometer, HR4000 from Ocean Optics.

Fig. 20 shows a photoionization detector 100, 200 as it can be used in the insulation fluid filler 30 from fig. 1 or in the electrical apparatus 1. Here, UV light from a light source 23 is propagated through the measurement cell 21 to ionize molecules of the insulation fluid 10. The degree of ionization can then be measured as an ion current by electrodes 22 and thus the mixing ratio can be derived.

Fig. 21 shows a pTp detector 100, 200 in bypass configuration, as it can be used in the insulation fluid filler 30 from Fig. 1 or - in a different configuration - also inside the electrical apparatus 1. Here, the pressure p , the temperature T , and the density ρ of a static, isothermal (cf. the heaters, diagonal lines) gas sample of the insulation fluid 10 are measured and the fluid component concentrations c_A and c_B (or the mixing ratio) can thus be determined. The valves 337 are periodically opened and closed to measure a fresh insulation fluid sample. Alternatively, such a pTp detector 100, 200 can also be used in an in-line configuration. With regard to this Fig. 21, this means that one valve 337 could be closed permanently or alternately to the other valve 337, or that only a single flange connection would be required.

Definitions:

The term "air" herein shall include "technical air", i.e. pressurized and dried ambient air, or "synthetic air", i.e. mixtures of nitrogen (N_2) and oxygen (O_2) with various mixing ratios, or ambient air.

The term "aliphatic" herein shall relate to both "linear aliphatic" and "branched aliphatic".

The term "fluid" herein shall relate to "a substance, such as a liquid [and/] or gas, that can flow,

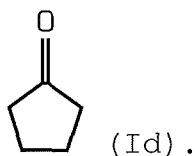
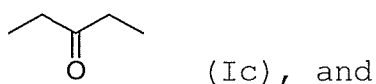
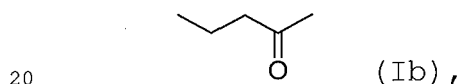
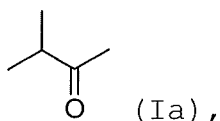
has no fixed shape, and offers little resistance to an external stress" (from <http://www.thefreedictionary.com/fluid>, accessed on 9/11/2011).

The term "high-voltage" herein shall relate to
5 voltages larger than 50 kV.

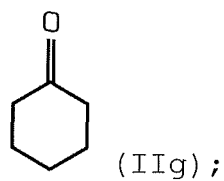
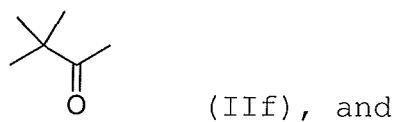
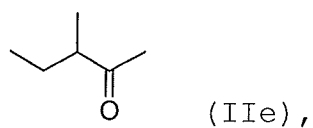
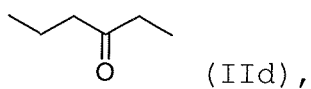
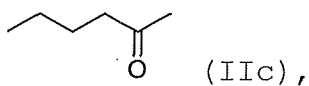
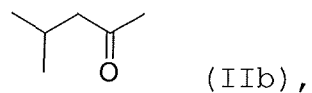
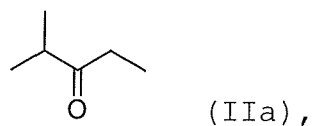
The term "medium-voltage" herein shall relate to voltages larger than 1 kV.

The compound class "hydrofluoroethers" herein relates to specific partially or fully fluorinated ethers
10 as, e.g., available from 3M.

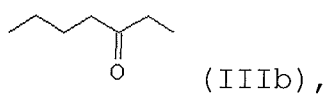
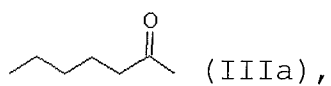
The compound "C5" herein particularly relates to a fluoroketone selected from the group consisting of the compounds defined by the following structural formulae in which at least one hydrogen atom, preferably all hydrogen
15 atoms, is/are substituted with a fluorine atom/ fluorine atoms:

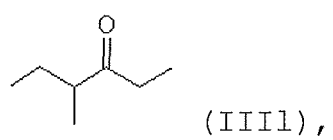
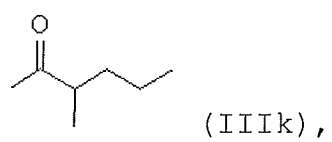
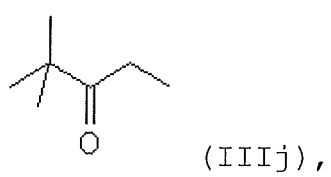
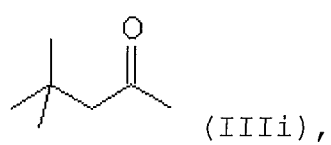
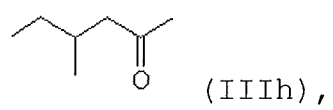
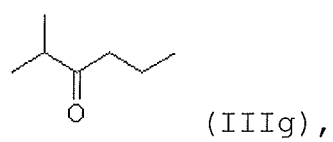
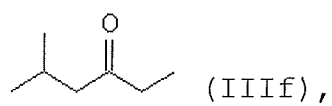
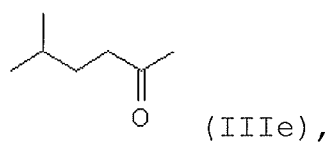
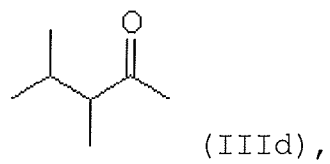
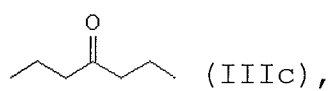


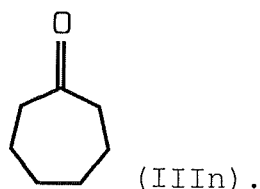
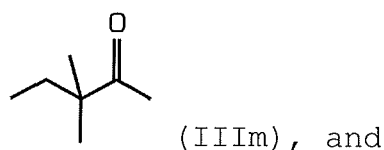
The compound "C6" herein particularly relates to a fluoroketone selected from the group consisting of the
25 compounds defined by the following structural formulae in which at least one hydrogen atom, preferably all hydrogen atoms, is/are substituted with a fluorine atom/ fluorine atoms:



The compound "C7" herein particularly relates to
 10 a fluoroketone selected from the group consisting of the
 compounds defined by the following structural formulae in
 which at least one hydrogen atom, preferably all hydrogen
 atoms, is/are substituted with a fluorine atom/ fluorine
 atoms:







Note:

5 C5 or "C5", C6 or "C6", C7 or "C7" etc. denote partially or fully fluorinated fluoroketones that have 5, 6, 7 etc. interconnected carbon atoms.

While there are shown and described presently preferred embodiments of the invention, it is to be distinctly understood that the invention is not limited thereto but may be otherwise variously embodied and practiced within the scope of the following claims.

15 Reference numbers

1:	electrical apparatus
2:	compartment of electrical apparatus 1
10:	insulation fluid
20 A:	first fluid component of insulation fluid 10
B:	second fluid component of insulation fluid 10
M1:	first amount of insulation fluid 10
M2:	second amount of insulation fluid 10
R1:	first mixing ratio of the first amount M1 of
25	the insulation fluid 10
R2:	second mixing ratio of the second amount M2 of
	the insulation fluid 10
T _{fill} :	filling temperature
C _A :	first concentration of first fluid component A
30 C _B :	second concentration of second fluid

		component B
	E_{bd} :	dielectric breakdown strength of insulation fluid
	21:	measurement cell
5	21a:	reference cell
	22:	electrodes
	23:	light source
	24:	lens
	25:	detector
10	26:	emission filter
	27:	mirror
	28:	beam splitter
	29:	band-pass filters
	30:	insulation fluid filler
15	31:	mixer
	32:	interface
	33:	fluid connector
	34:	analysis and control unit
	35, 36:	mass flow meter and regulator
20	100, 200:	first and second sensor
	301, 302:	fluid component reservoirs
	303:	pump
	304:	pressure regulator
	305:	circulator
25	310:	heater
	331:	carrier gas reservoir
	332:	sample injector
	333:	column
	334:	detector
30	335:	mass spectrometer
	337:	valve

Claims

1. A method for filling a first amount (M1) of an insulation fluid (10) into a compartment (2) of a fluid-insulated electrical apparatus (1), in particular of a gas-insulated medium or high voltage switchgear (1), wherein the method is carried out at a filling temperature (T_{fill}), wherein the insulation fluid (10) comprises at least a first fluid component (A) and a second fluid component (B), wherein the method comprises method elements of
- mixing the at least two fluid components (A, B) with a first mixing ratio (R1) for yielding the first amount (M1) of the insulation fluid (10),
 - deriving
 - a) the first mixing ratio (R1) of the first amount (M1) of the insulation fluid (10) by means of a first sensor (100) and/or
 - b) a second mixing ratio (R2) of a second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1) by means of a second sensor (200), and
 - filling the first amount (M1) of the insulation fluid (10) into the compartment (2) of the electrical apparatus (1),
- wherein the first mixing ratio (R1) of the first amount (M1) of the insulation fluid (10) is controlled such that condensation temperatures of the fluid components (A, B) in the first amount (M1) of the insulation fluid (10) are below the filling temperature (T_{fill}), and
- wherein the first mixing ratio (R1) and the first amount (M1) of the insulation fluid (10) are controlled using

* the second mixing ratio (R2) and the second amount (M2) of the insulation fluid (10) and/or using

* a target mixing ratio (R) and a target amount (M) of the insulation fluid (10).

5

2. The method of claim 1, wherein a filling pressure (p_{fill}) of the insulation fluid (10) in the compartment (2) after the step of filling the first amount (M1) of the insulation fluid (10) into the compartment
10 (2) is above 1 bar, preferably above 2 bars, more preferably above 5 bars, at an insulation fluid temperature of 20°C.

3. The method of any of the preceding claims
15 further comprising a method element of

- bringing the fluid components (A, B) into gaseous states.

4. The method of claim 3, wherein the step of
20 bringing the fluid components (A, B) into gaseous states is carried out prior to carrying out the step of mixing the fluid components (A, B).

5. The method of any of the claims 3 to 4,
25 wherein the first fluid component (A) is in a liquid state at the filling temperature (T_{fill}) and at a pressure of 1 bar, and wherein the second fluid component (B) is in a gaseous state at the filling temperature (T_{fill}) and at a pressure between 5 bar and 200 bar, and wherein
30 the first and the second fluid components (A, B) are brought into gaseous states and then mixed at the filling temperature (T_{fill}) and at a pressure between 3 bar and 10 bar.

35 6. The method of any of the preceding claims, further comprising a method element of

- homogenizing the first amount (M1) of the insulation fluid (10) for reducing a mixture fluctuation and/or a density fluctuation in the first amount (M1), and/or a method element of

5 - homogenizing the second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1) for reducing a mixture fluctuation and/or a density fluctuation in the second amount (M1),

10 and in particular wherein the step or the steps of homogenizing the first and/or the second amount (M1, M2) is or are carried out before deriving the first mixing ratio (R1) and/or before deriving the second mixing ratio (R2).

15 7. The method of any of the preceding claims, further comprising a method element of

 - reducing the second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1), and/or

20 - reducing an amount of a filling gas in the compartment (2) of the electrical apparatus (1),

 in particular prior to carrying out the step of filling the first amount (M1) of the insulation fluid (10) into the compartment (2) of the electrical apparatus
25 (1).

 8. The method of any of the preceding claims, wherein at least the method elements of

30 - mixing the fluid components (A, B) at the first mixing ratio (R1), and

 - deriving

 a) the first mixing ratio (R1) of the first amount (M1) of the insulation fluid (10) and/or

35 b) the second mixing ratio (R2) of the second amount (M2) of the insulation fluid (10), and

- filling the first amount (M1) of the insulation fluid (10) into the compartment (2) of the electrical apparatus (10)

are carried out repeatedly.

5

9. The method of claim 8, wherein the step of filling the first amounts (M1) of the insulation fluid (10) into the compartment (2) are carried out against increasing second amounts (M2) of the insulation fluid (10) in the compartment (2).

10

10. The method of any of the preceding claims, wherein the first sensor (100) and/or the second sensor (200) comprises at least one of the group of:

15

- a gas chromatograph,
- an optical sensor,
- an acoustic and/or a photoacoustic sensor,
- a pressure sensor, a temperature sensor, and a density sensor,

20

- a pressure sensor, a temperature sensor, and a speed of sound sensor,

- a pressure sensor, a temperature sensor, and a viscosity sensor, and

25

- a pressure sensor, a temperature sensor, and a thermal conductivity sensor.

11. The method of any of the preceding claims, further comprising a method element of

30

- deriving a mass flow of at least one of the fluid components (A, B),

and in particular the method comprising a method element of

35

- deriving a mass flow of the first fluid component (A) in the first amount (M1) and deriving a mass flow of the second fluid component (B) in the first amount (M1) prior to or during the step of filling the

first amount (M1) of the insulation fluid (10) into the compartment (2) of the electrical apparatus (10).

12. The method of any of the preceding
5 claims, wherein the first fluid component (A) is selected from the group consisting of:

- sulfur hexafluoride,
- partially or fully fluorinated ethers, in particular hydrofluoroethers, hydrofluoro monoethers, hydrofluoro monoethers containing at least 3 carbon atoms, perfluoro monoethers, or perfluoro monoethers containing at least 4 carbon atoms,
- partially or fully fluorinated ketones, in particular hydrofluoro monoketones, perfluoro monoketones, perfluoro monoketones comprising at least 5 carbon atoms, or perfluoro monoketones comprising exactly 5 or 6 or 7 or 8 carbon atoms, and

- mixtures thereof, and
wherein the second fluid component (B) is selected from the group consisting of:

- nitrogen,
- oxygen,
- carbon dioxide,
- nitric oxide,
- nitrogen dioxide,
- nitrous oxide,
- argon,
- methanes, in particular partially or fully halogenated methanes, in particular tetrafluoromethane or trifluoroiodomethane,
- air, in particular technical air or synthetic air, and
- mixtures thereof.

13. The method of claim 12, wherein the first fluid component (A) is selected from the group consisting of:

- cyclic and/or aliphatic fluoropentanones, preferably cyclic and/or aliphatic perfluoropentanones, more preferably 1,1,1,3,4,4,4-heptafluoro-3-(tri-fluoromethyl)butan-2-one,
- 5 - cyclic and/or aliphatic fluorohexanones, preferably cyclic and/or aliphatic perfluorohexanones, more preferably 1,1,1,2,4,4,5,5,5-nonafluoro-4-(tri-fluoromethyl)pentan-3-one,
- cyclic and/or aliphatic fluoroheptanones,
- 10 preferably cyclic and/or aliphatic perfluoroheptanones,
- sulfur hexafluoride, and
- hydrofluoroethers.

14. The method of any of the claims 12 to 13,
15 wherein the second fluid component (B) consists of

nitrogen and oxygen with relative partial pressures between $p(\text{N}_2)/(p(\text{O}_2)+p(\text{N}_2))=0.7$, $p(\text{O}_2)/(p(\text{O}_2)+p(\text{N}_2))=0.3$ and $p(\text{N}_2)/(p(\text{O}_2)+p(\text{N}_2))=0.95$, $p(\text{O}_2)/(p(\text{O}_2)+p(\text{N}_2))=0.05$ or

20 carbon dioxide and oxygen with relative partial pressures between $p(\text{CO}_2)/(p(\text{O}_2)+p(\text{CO}_2))=0.6$, $p(\text{O}_2)/(p(\text{O}_2)+p(\text{CO}_2))=0.4$ and $p(\text{CO}_2)/(p(\text{O}_2)+p(\text{CO}_2))=0.99$, $p(\text{O}_2)/(p(\text{O}_2)+p(\text{CO}_2))=0.01$, or

25 carbon dioxide and nitrogen with relative partial pressures between $p(\text{CO}_2)/(p(\text{N}_2)+p(\text{CO}_2))=0.1$, $p(\text{N}_2)/(p(\text{N}_2)+p(\text{CO}_2))=0.9$ and $p(\text{CO}_2)/(p(\text{N}_2)+p(\text{CO}_2))=0.9$, $p(\text{N}_2)/(p(\text{N}_2)+p(\text{CO}_2))=0.1$, and

wherein the first fluid component (A) comprises at least one of the group consisting of:

30 1,1,1,3,4,4,4-heptafluoro-3-(tri-fluoromethyl)butan-2-one with a partial pressure between 0.1 bar and 0.7 bar at a temperature of 20°C,

35 1,1,1,2,4,4,5,5,5-nonafluoro-4-(tri-fluoromethyl)pentan-3-one with a partial pressure between 0.01 bar and 0.3 bar at a temperature of 20°C,

sulfur hexafluoride with a partial pressure between 0.1 bar and 2 bar at a temperature of 20°C, and

hydrofluoroethers with a partial pressure between 0.2 bar and 1 bar at a temperature of 20°C.

15. The method of any of the claims 12 to 14,
 5 wherein the second fluid component (B) comprises
 nitrogen and oxygen with relative partial pressures between $p(N_2)/(p(O_2)+p(N_2))=0.75$, $p(O_2)/(p(O_2)+p(N_2))=0.25$ and $p(N_2)/(p(O_2)+p(N_2))=0.90$, $p(O_2)/(p(O_2)+p(N_2))=0.10$ and
 10 wherein the first fluid component (A) comprises 1,1,1,3,4,4,4-heptafluoro-3-(tri-fluoromethyl)butan-2-one with a partial pressure between 0.25 bar and 0.5 bar and/or the fluid component 1,1,1,2,4,4,5,5,5-nona-fluoro-4-(tri-fluoromethyl)pentan-3-one with a partial pressure between 0.02 bar and 0.3 bar at a temperature of 20°C.

16. The method of any of the preceding claims, further comprising the method elements of
 20 - deriving a first concentration (c_A) of the first fluid component (A) in a or the second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1) and
 - deriving a second concentration (c_B) of the
 25 second fluid component (B) in a or the second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1).

17. The method of any of the preceding
 30 claims, further comprising a method element of
 - deriving a dielectric breakdown strength E_{bd} of a second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1) using a first concentration (c_A) of the first fluid component (A) and using a second concentration (c_B) of the
 35 second fluid component (B), in particular according to

$$E_{bd} = S(c_A, c_B) \sum_{i=A,B} c_i E_{crit,i}$$

with $E_{\text{crit},A}$ and $E_{\text{crit},B}$ being fluid-component-specific critical field strengths of the fluid components A and B; with c_A and c_B being the first and second concentrations of the first and second fluid components A and B; with $S(c_A, c_B)$ being a synergy parameter; and with i being an index for the fluid components A and B.

10 18. The method of any of the preceding claims, comprising a further method element of

- deriving an operating state (O) of the electrical apparatus (1) using a first concentration (c_A) of the first fluid component (A) and using a second concentration (c_B) of the second fluid component (B) in the second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1), and/or comprising a further step of

20 - deriving an operating state (O) of the electrical apparatus (1) using a dielectric breakdown strength (E_{bd}) of the second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1).

25 19. An insulation fluid filling apparatus (30) for filling at least a first amount (M1) of an insulation fluid (10) into a compartment (2) of a fluid-insulated electrical apparatus (1), in particular of a gas-insulated medium or high voltage switchgear (1), according to any of the preceding claims, the insulation fluid filler (30) comprising:

- a mixer (31) for mixing at least two fluid components (A, B) at a first mixing ratio (R1),
- a first sensor (100) for deriving the first mixing ratio (R1) of the first amount (M1) of the insulation fluid (10), and/or an interface (32) for receiving a sensor signal indicative of a second mixing ratio (R2) of

a second amount (M2) of the insulation fluid (10) in the compartment (2) of the electrical apparatus (1),

- a fluid connector (33) for connecting the insulation fluid filler (30) to the electrical apparatus (1) and for transferring the first amount (M1) of the insulation fluid (10) from the insulation fluid filler (30) to the electrical apparatus (1), and
- an analysis and control unit (34) adapted and structured to carry out the method element of the method of any of the preceding claims.

20. The insulation fluid filling apparatus (30) of claim 19, wherein the analysis and control unit (34) comprises a computer program element comprising computer program code means for, when executed by a processing unit, implementing a method of any of the claims 1 to 18.

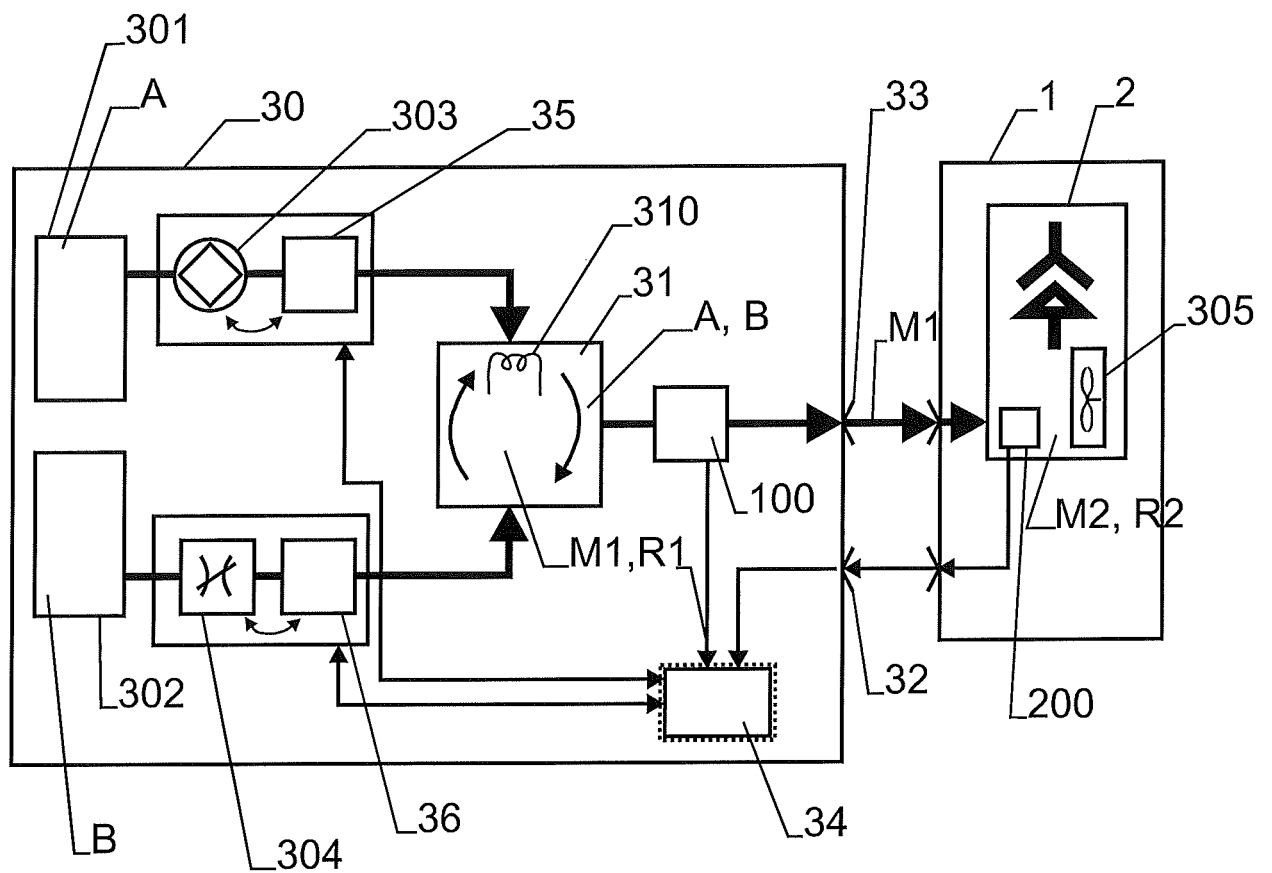


Fig. 1

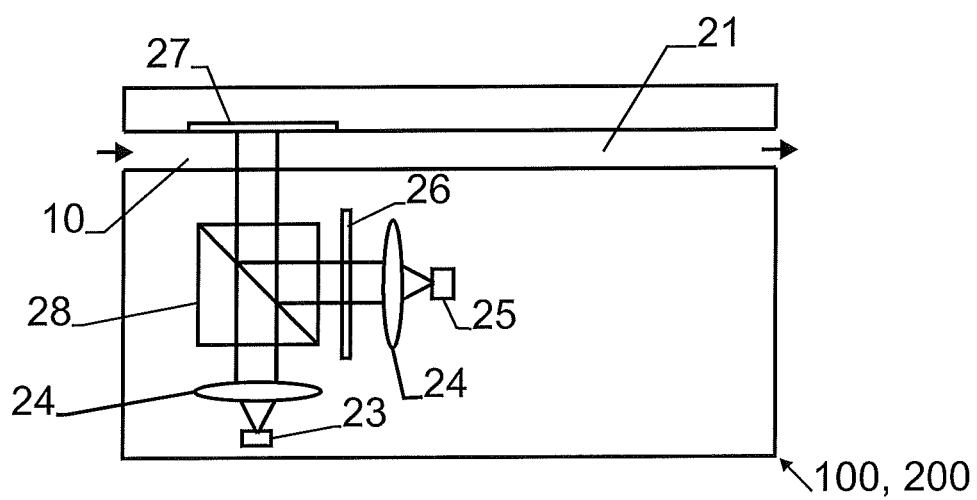


Fig. 2

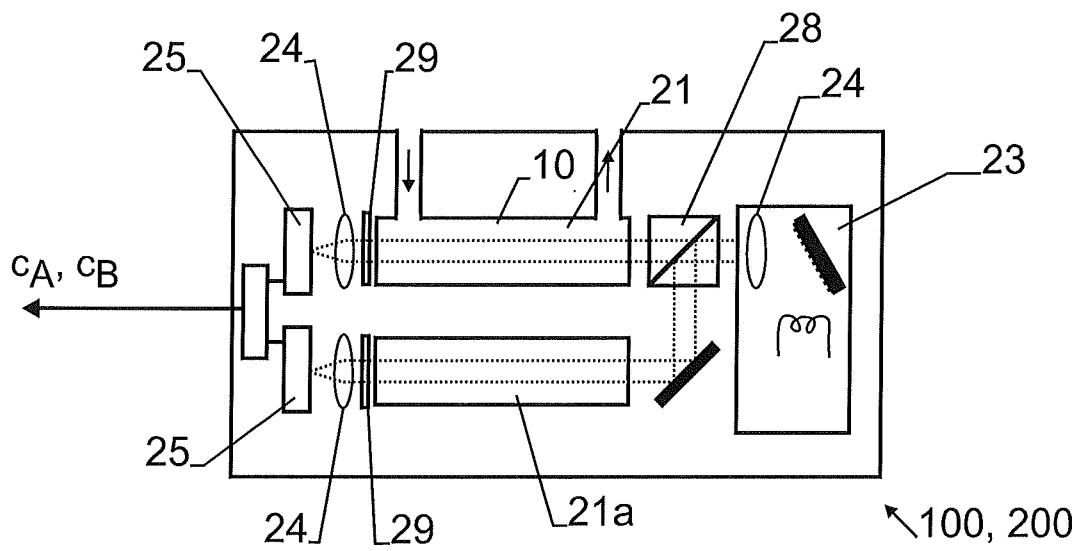


Fig. 3

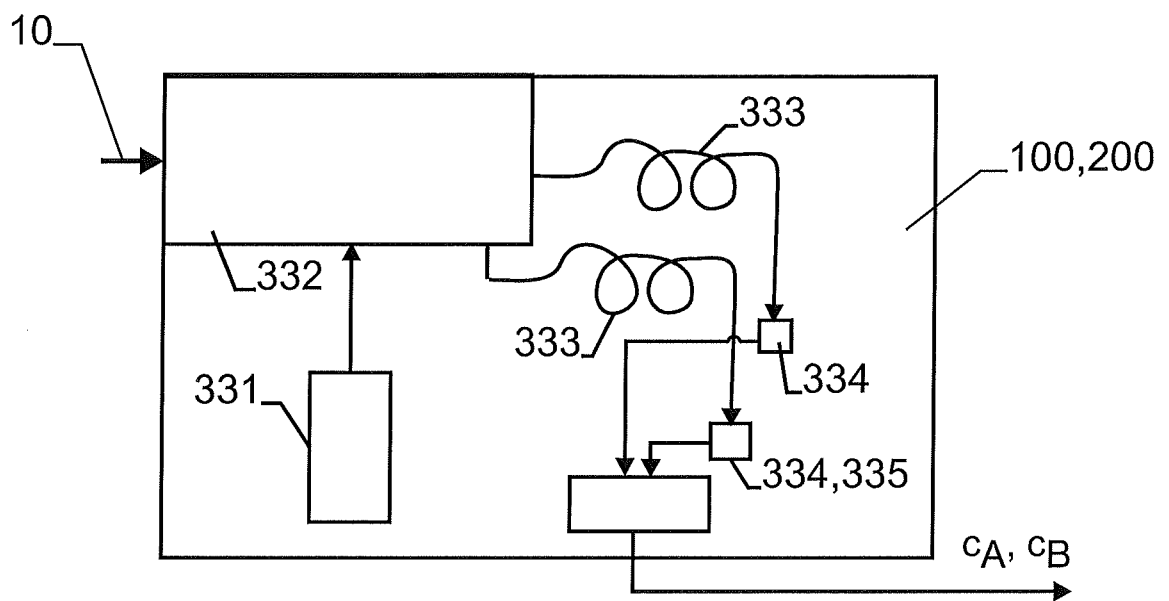


Fig. 4

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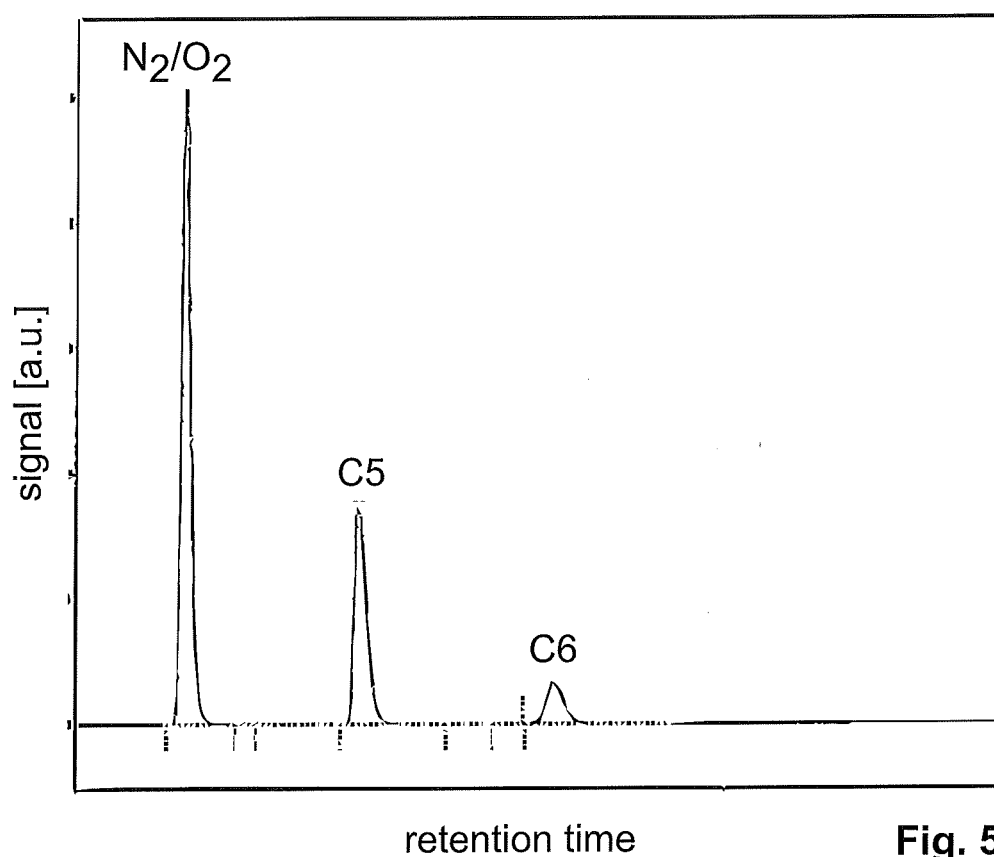


Fig. 5

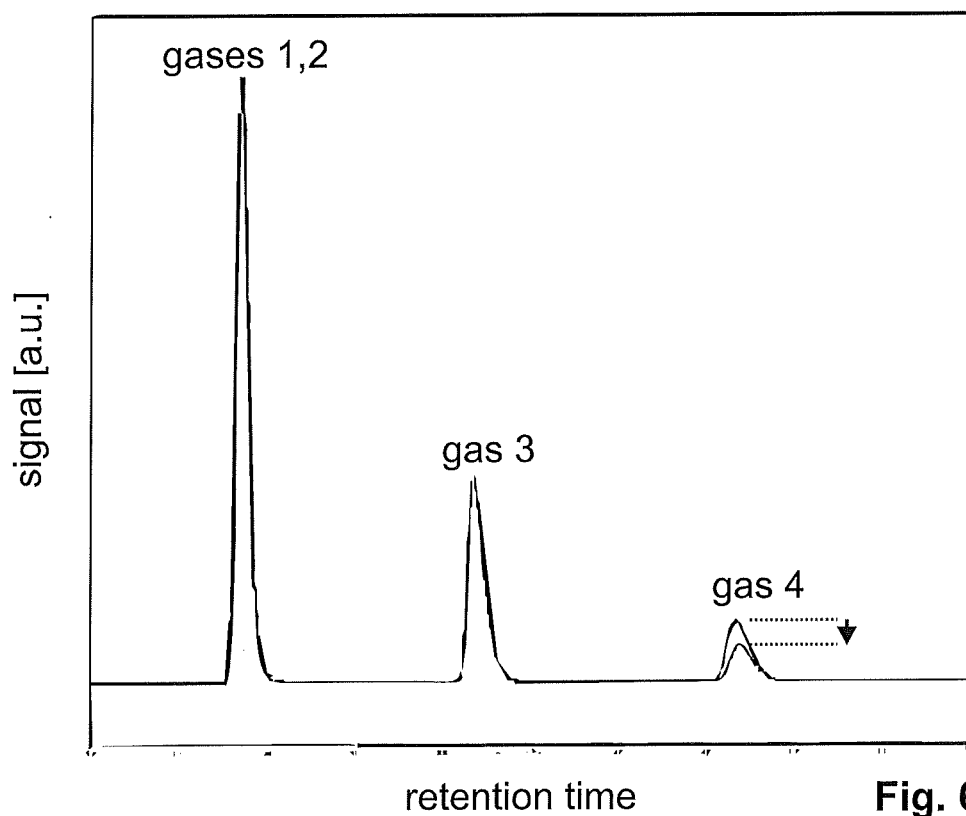
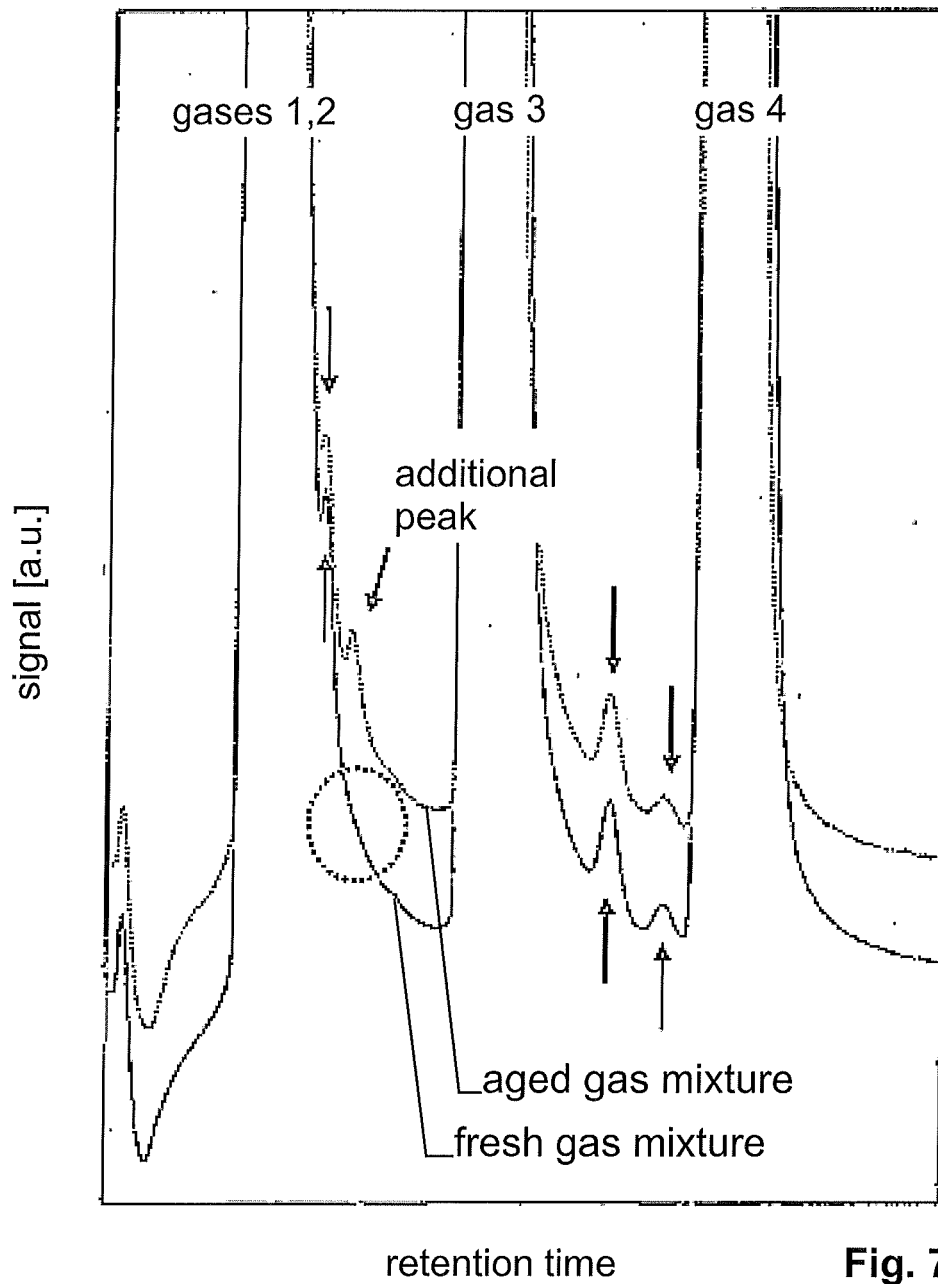


Fig. 6

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**Fig. 7**

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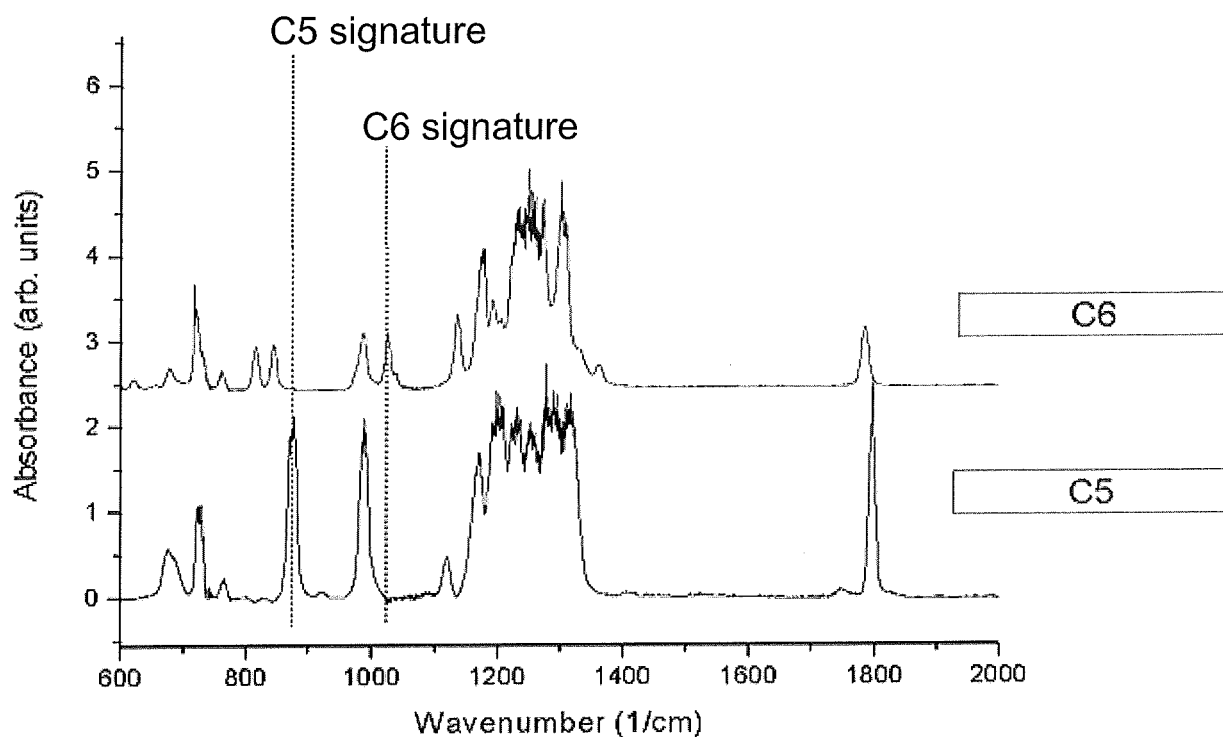


Fig. 8

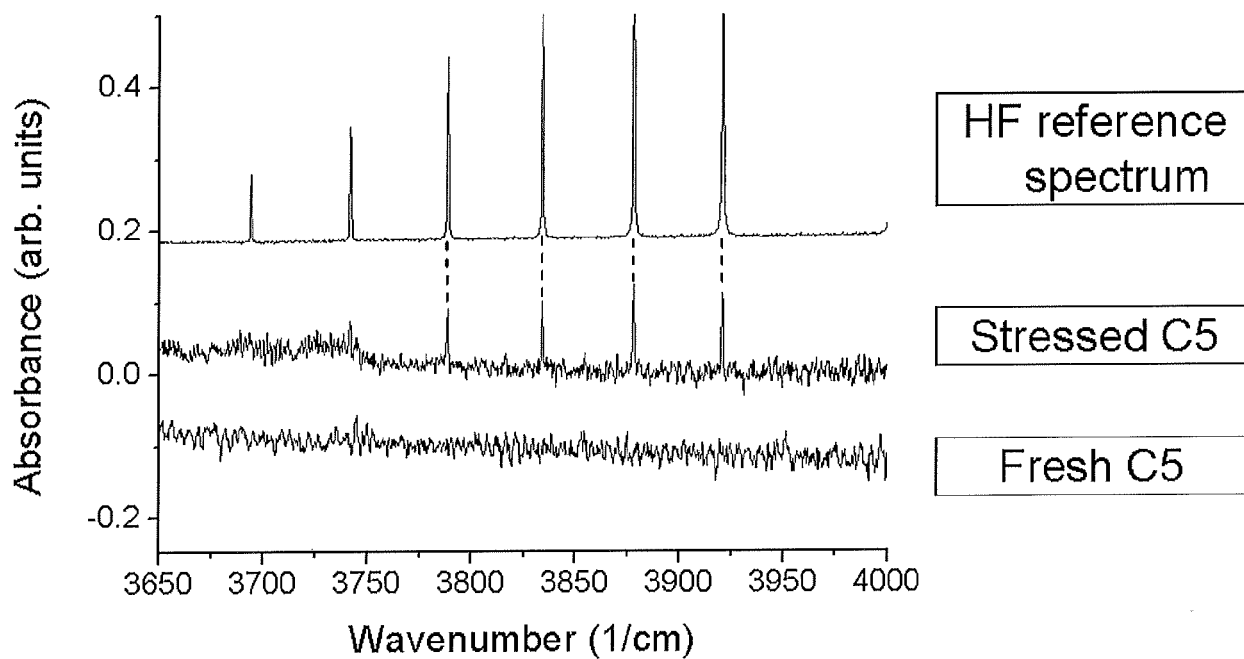
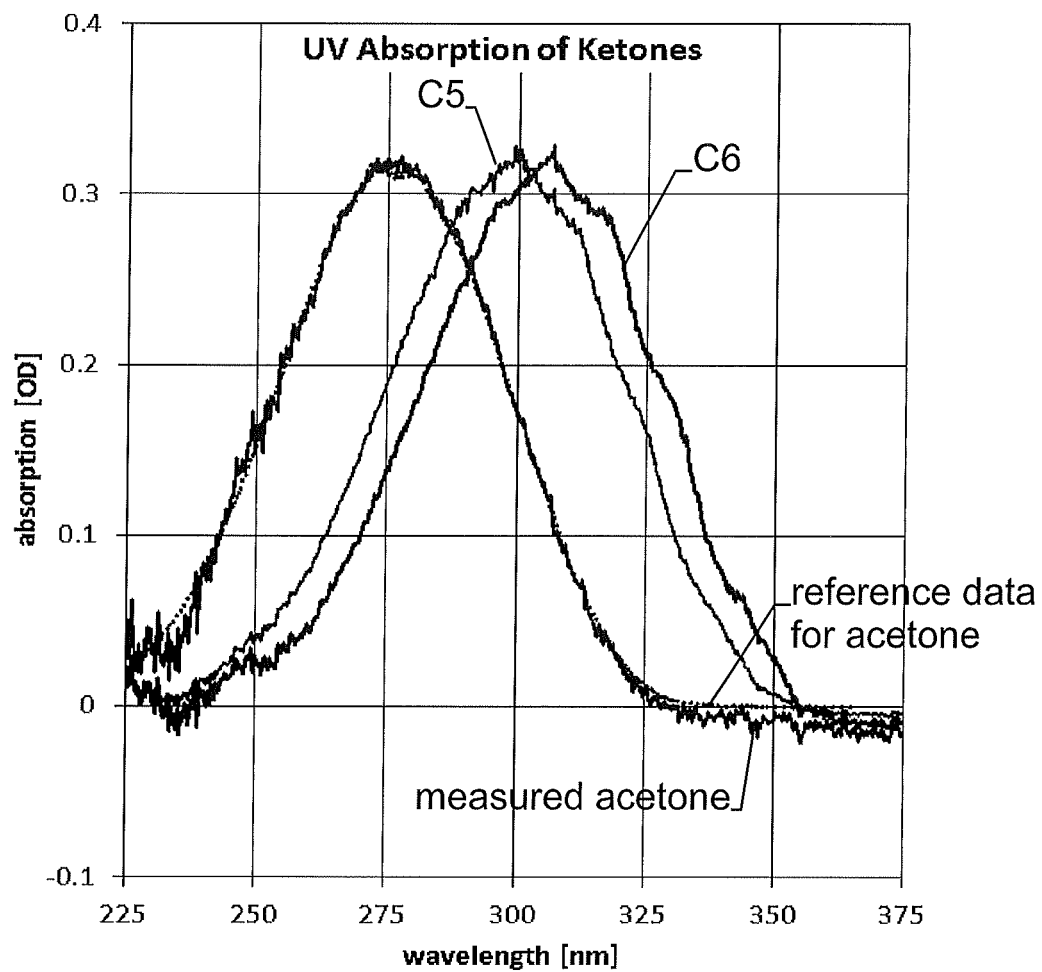


Fig. 9

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**Fig. 10**

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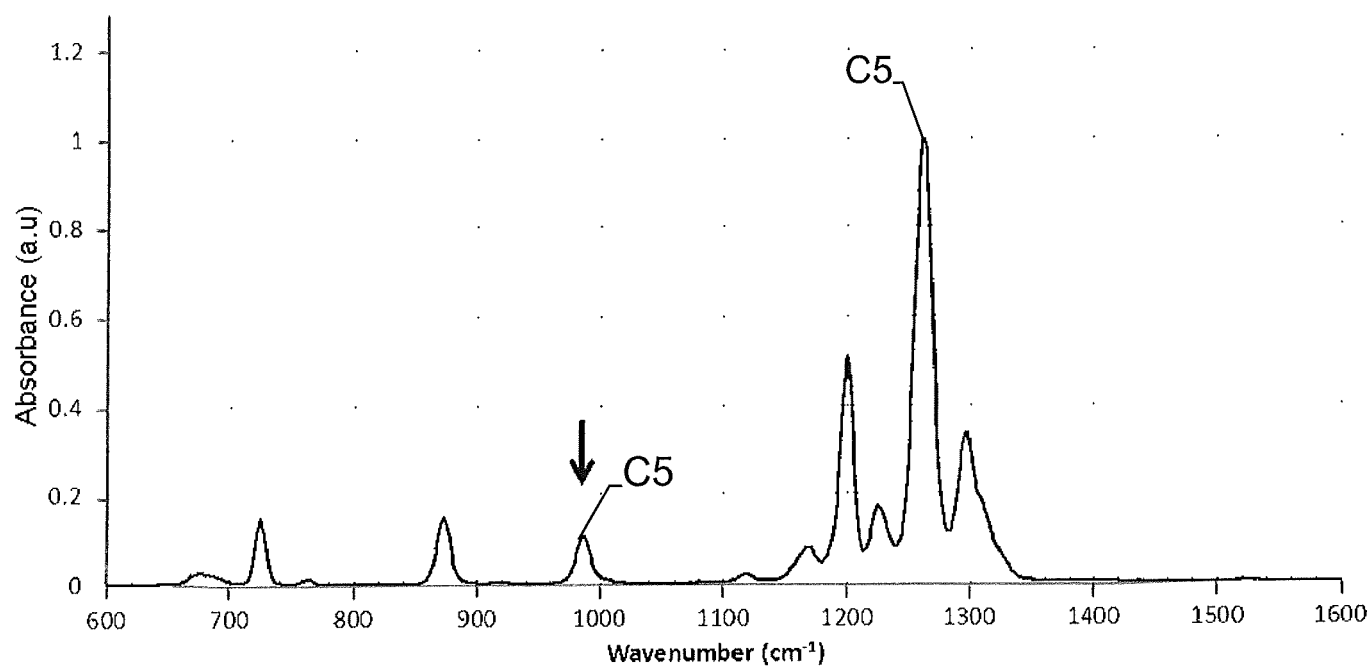


Fig. 11

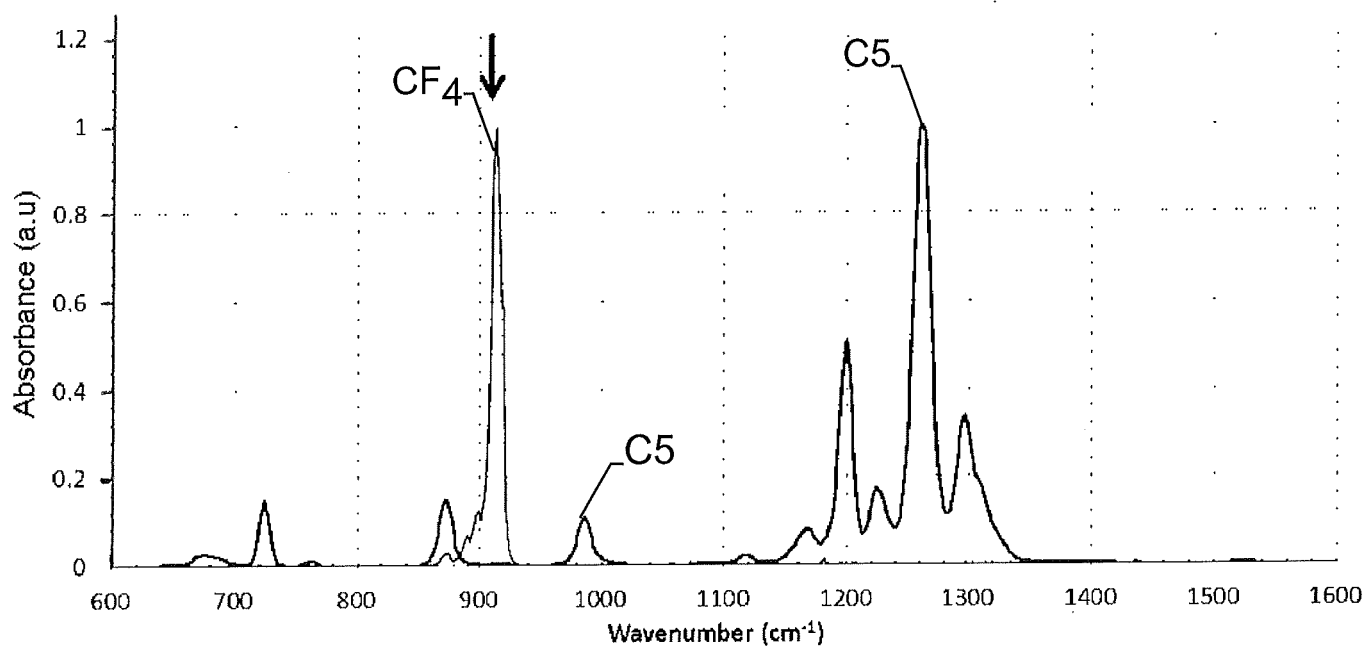


Fig. 12

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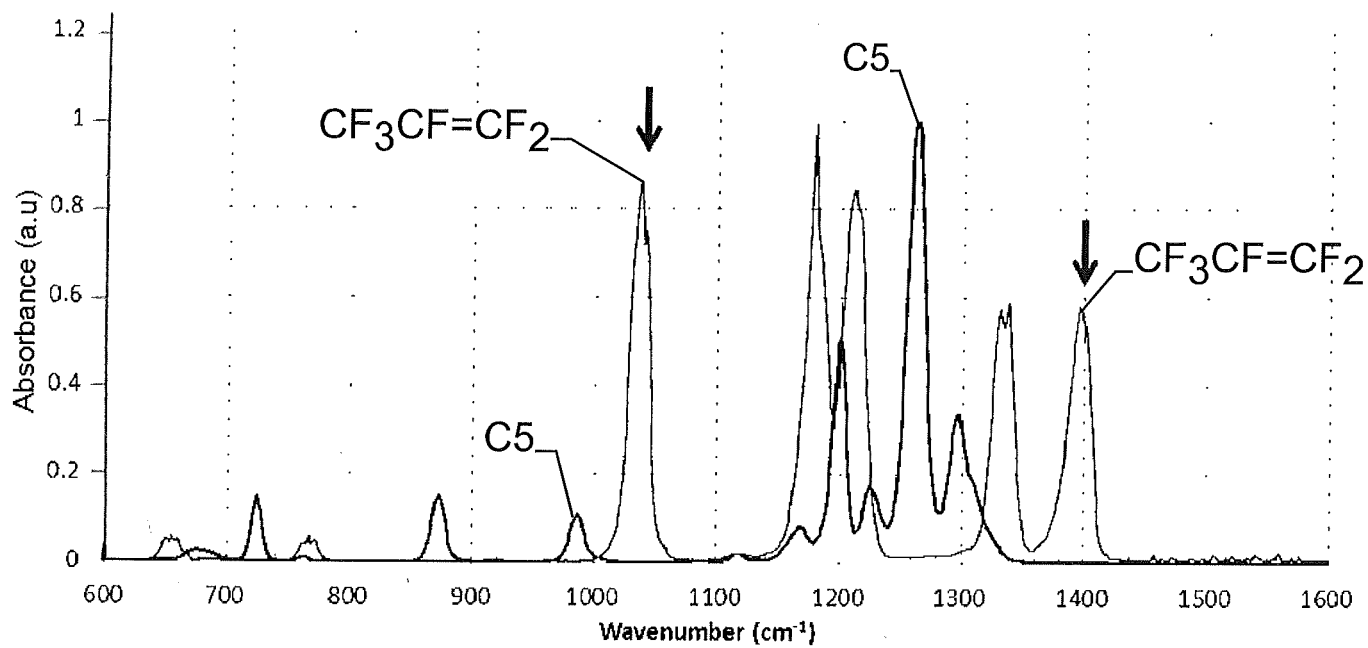


Fig. 13

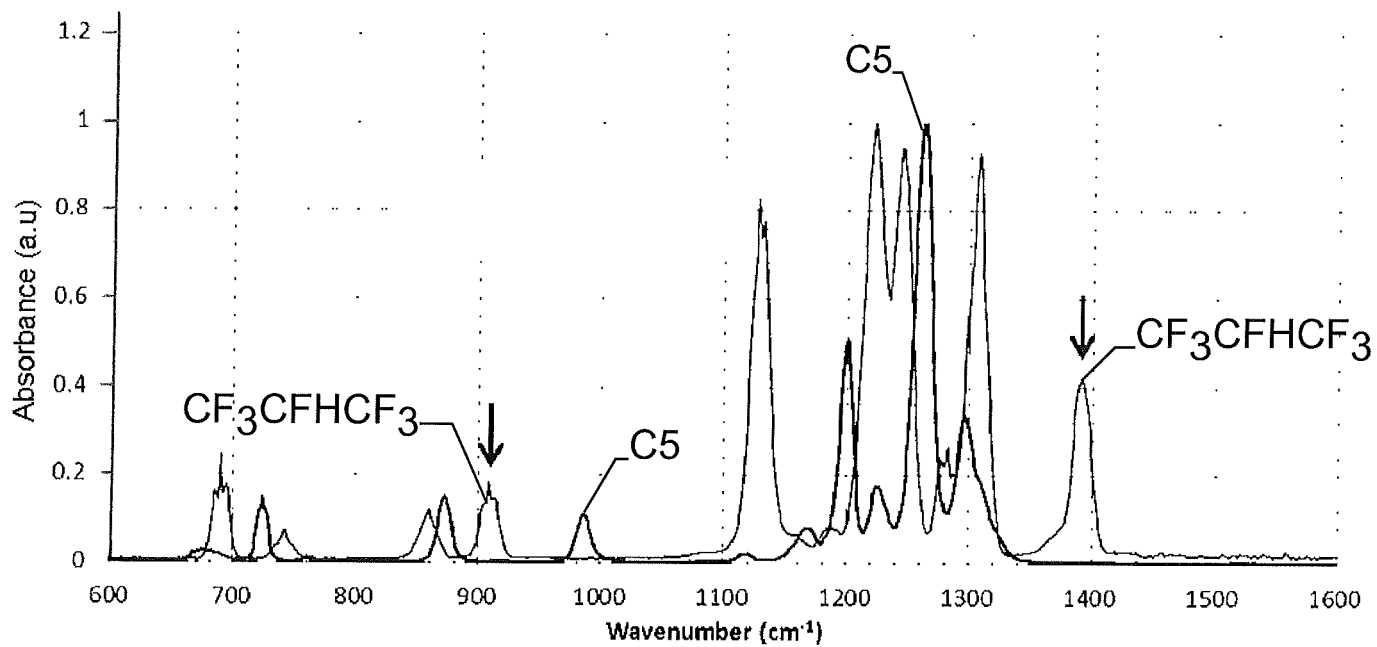


Fig. 14

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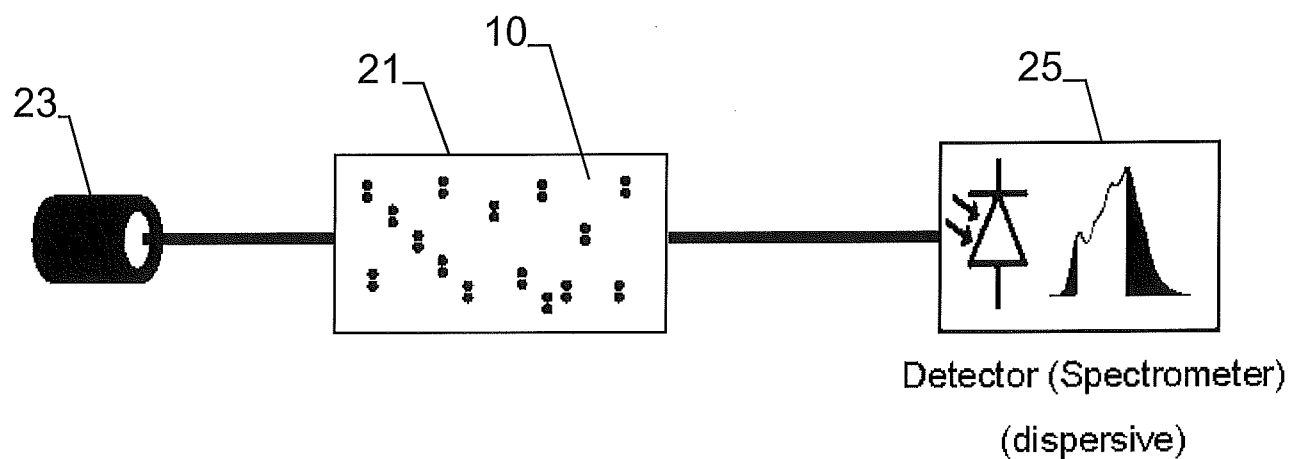


Fig. 15

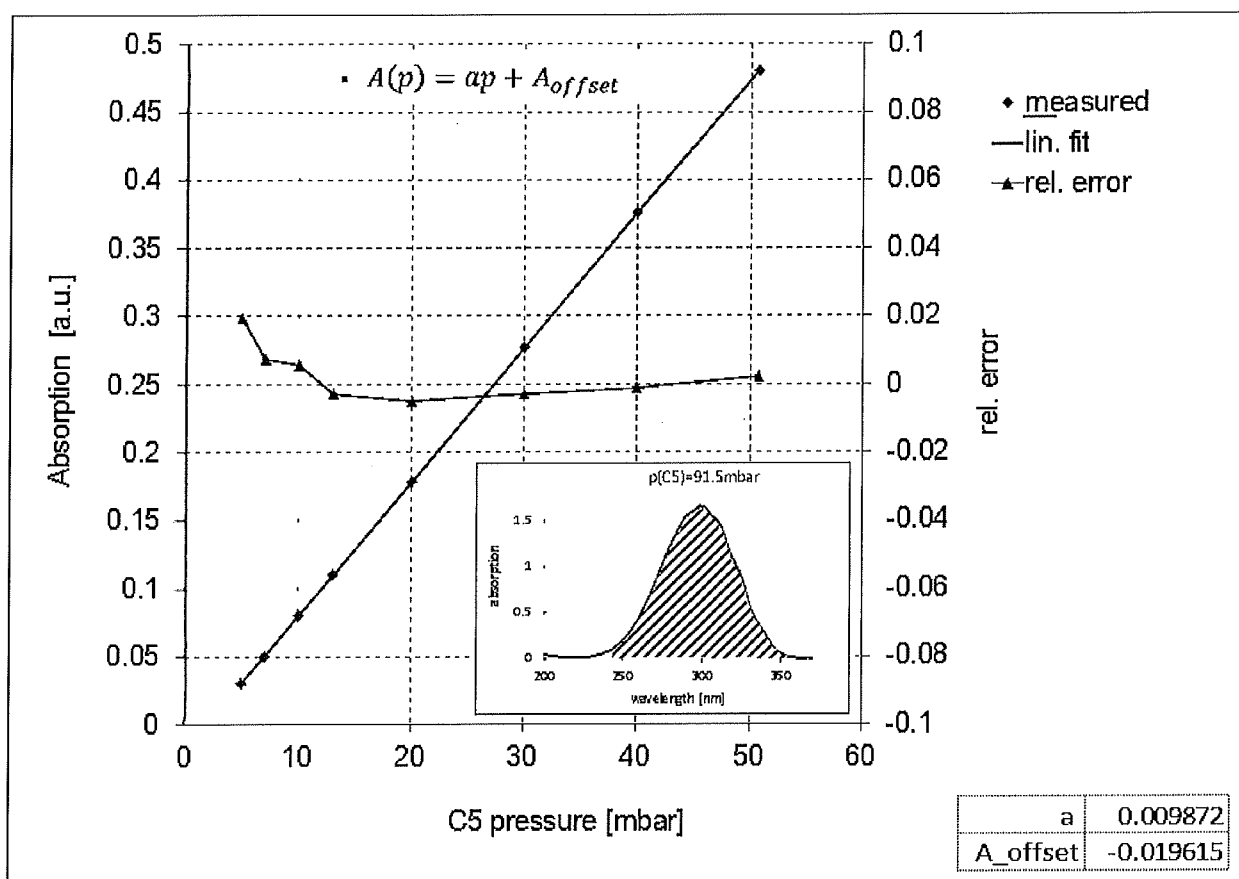


Fig. 16

10/12

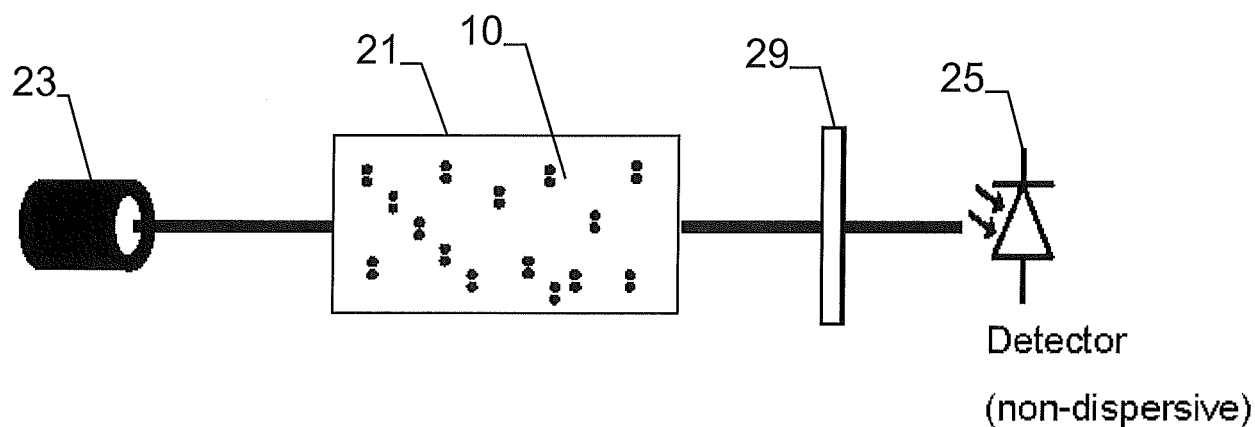


Fig. 17

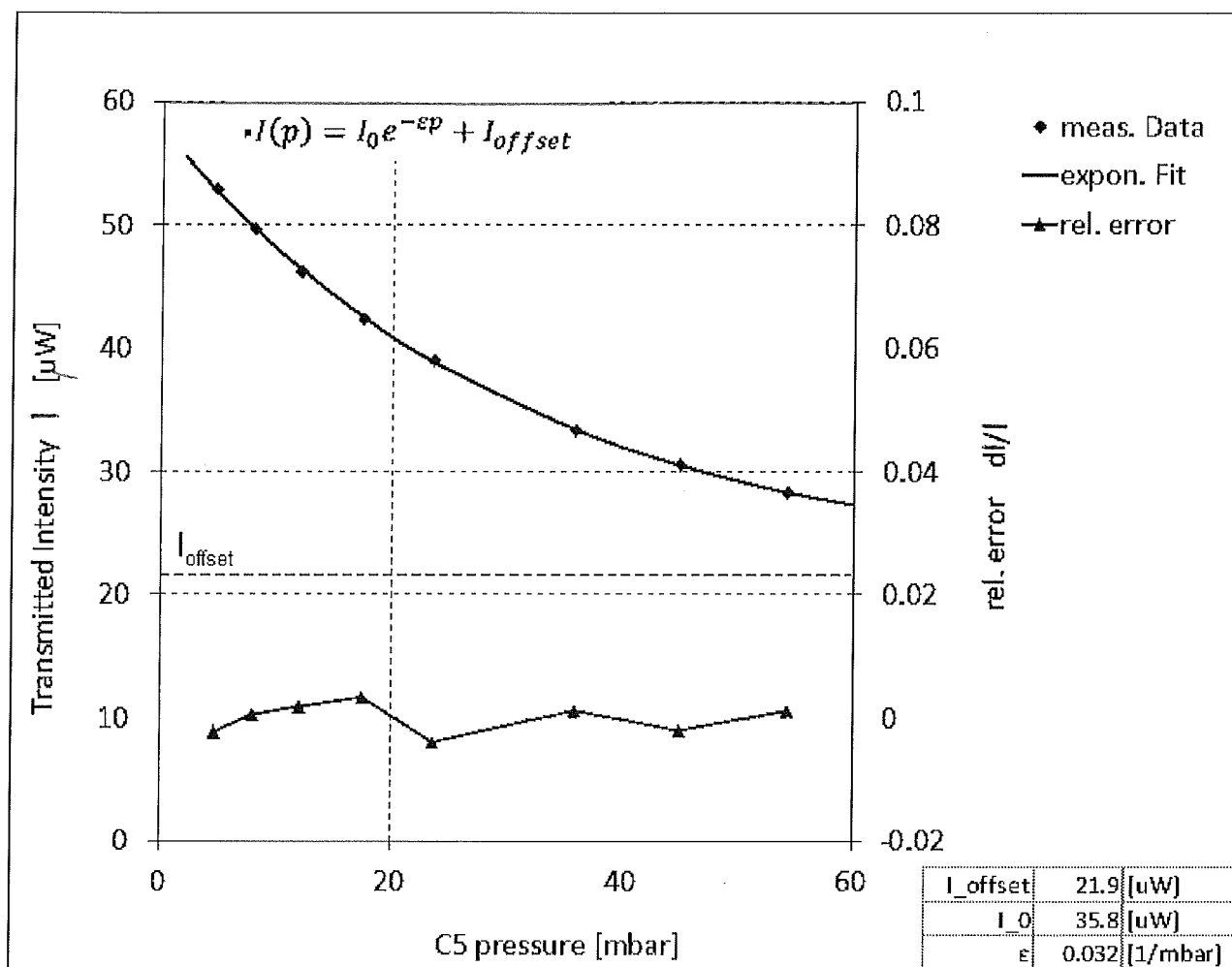


Fig. 18

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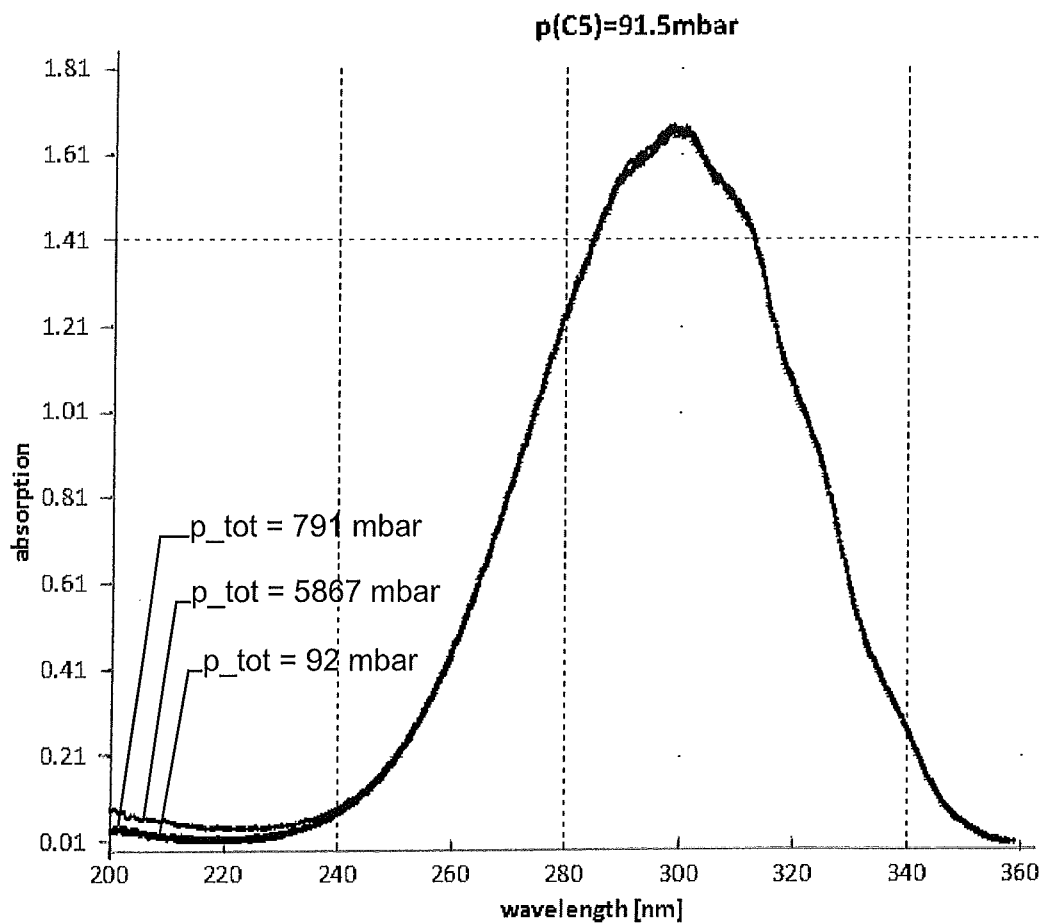


Fig. 19

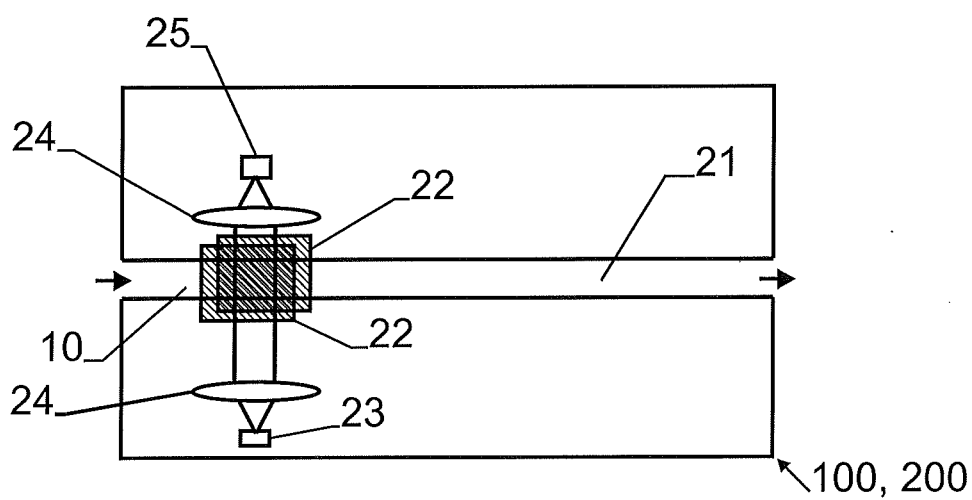
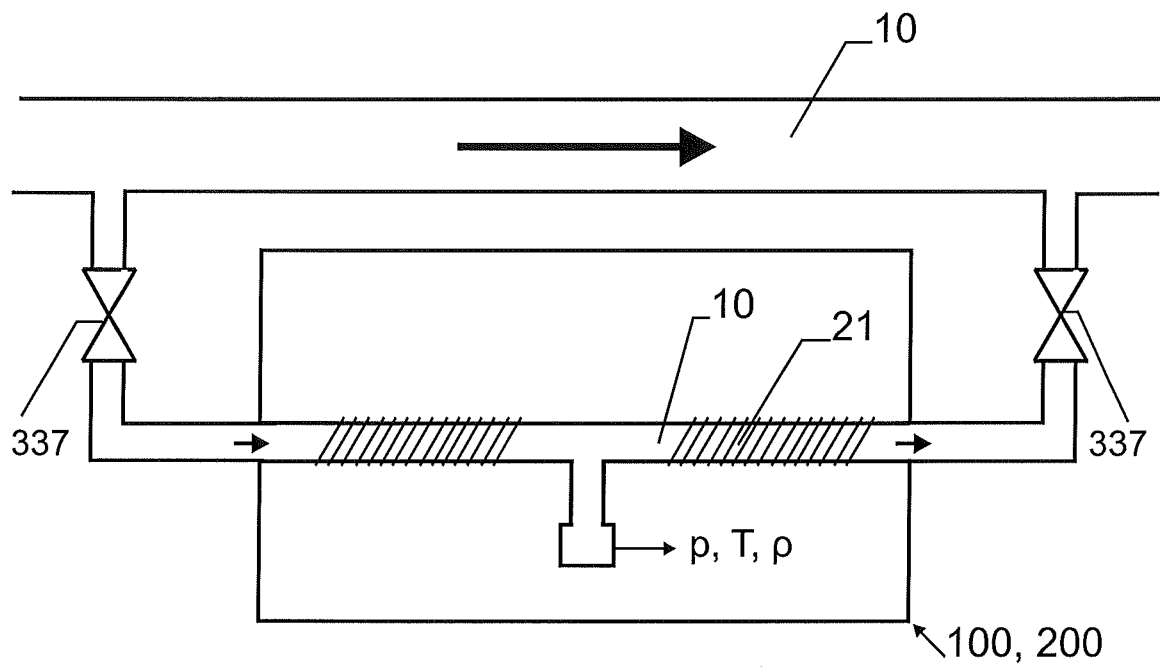


Fig. 20

**Fig. 21**

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/067222

A. CLASSIFICATION OF SUBJECT MATTER INV. H01H33/22 H01B3/56 H01H33/56 H02B13/055 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H01H H01B H02B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A A A A	EP 0 476 502 A2 (HITACHI LTD [JP]) 25 March 1992 (1992-03-25) claim 1; figure 1 ----- EP 0 128 588 A1 (MITSUBISHI ELECTRIC CORP [JP]) 19 December 1984 (1984-12-19) page 4, paragraph 2 - paragraph 4 ----- EP 0 203 252 A2 (FELTEN & GUILLEAUME ENERGIE [DE]) 3 December 1986 (1986-12-03) page 2, paragraph 4 ----- US 4 990 831 A (THAYER III WILLIAM J [US]) 5 February 1991 (1991-02-05) abstract ----- -/-	1,10,12 19 1,12,19 1 1,3,4
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search	Date of mailing of the international search report	
31 May 2013	06/06/2013	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Socher, Günther	

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/067222

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2000 164040 A (HITACHI LTD) 16 June 2000 (2000-06-16) abstract	1,10
A	----- ZEISEL D ET AL: "A precise and robust quartz sensor based on tuning fork technology for (SF6)-gas density control", SENSORS AND ACTUATORS A, ELSEVIER SEQUOIA S.A., LAUSANNE, CH, vol. 80, no. 3, 1 March 2000 (2000-03-01), pages 233-236, XP004192111, ISSN: 0924-4247, DOI: 10.1016/S0924-4247(99)00345-3 -----	1,10

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2012/067222

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0476502	A2	25-03-1992	CA 2051215 A1 18-03-1992
			CN 1059994 A 01-04-1992
			DE 69124321 D1 06-03-1997
			DE 69124321 T2 28-08-1997
			EP 0476502 A2 25-03-1992
			JP 2997027 B2 11-01-2000
			JP H04125020 A 24-04-1992
			US 6063997 A 16-05-2000
EP 0128588	A1	19-12-1984	CA 1223052 A1 16-06-1987
			DE 3473962 D1 13-10-1988
			EP 0128588 A1 19-12-1984
			JP S602011 A 08-01-1985
			US 4565901 A 21-01-1986
EP 0203252	A2	03-12-1986	DE 3518932 A1 27-11-1986
			EP 0203252 A2 03-12-1986
			JP S61273109 A 03-12-1986
US 4990831	A	05-02-1991	NONE
JP 2000164040	A	16-06-2000	JP 4244081 B2 25-03-2009
			JP 2000164040 A 16-06-2000