## SPECTANO 100 – Application Note

# Dielectric Analysis of Insulation Liquids


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**Note**: Basic procedures such as setting-up and adjusting the SPECTANO 100 are described in the SPECTANO 100 user manual. You can download the SPECTANO 100 user manual on our download area at https://www.omicron-lab.com/

**Note**: All measurements in this application note have been performed with the SPECTANO Analyzer Suite V1.00. Use this version or a higher version to perform the measurements shown in this document. You can download the latest version on our download area at https://www.omicron-lab.com/

# 1 Measurement Task

In this document, we show how the dissipation factor and the conductivity of an insulation liquid can be measured using SPECTANO 100. The CP TC12 dielectric oil sample test cell of OMICRON electronics was used to measure the characteristics of mineral transformer oil (new mineral oil without any contaminations).

This application note provides only information on how to use SPECTANO 100 together with the TC CP 12 oil sample test cell and how to determine the specific conductivity σ(ω) and resistivity R(ω). For more information on the analysis of dielectric material curves see our SPECTANO 100 videos on the SPECTANO 100 Knowledge and Applications area located at https://www.omicron-lab.com/

# 2 Safety Instructions

**WARNING**

**Death or serve injury caused by high voltage or current**

Before starting a measurement, read the safety rules and operation and connection instructions in the SPECTANO User Manual and observe the application specific safety instructions in this document when performing measurements to protect yourself from high-voltage hazards.

# 3 Requirements to perform accurate dielectric material analysis

The measurement error of dielectric properties is not only caused by capacitance measurement errors, but also by

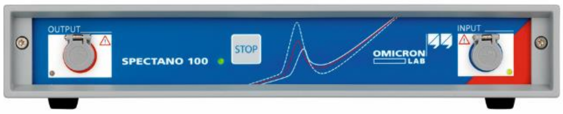
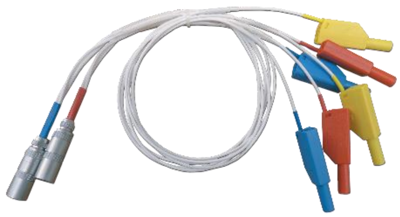
- the presence of conductive contaminations or moisture on the test cell or the material sample surface,
- the test cell construction,
- and the measurement setup itself.

Therefore, we recommend to comply with the requirements to perform accurate dielectric material analysis outlined in the application note **Requirements to perform accurate dielectric material analysis**[1].

[1] All SPECTANO 100 application notes and further video tutorials can be found on the SPECTANO 100 *Knowledge and Applications* area located at https://www.omicron-lab.com/.

# 4 Measurement Equipment

The measurement setup used in this application note consists of the following items:

| | |
|---|---|
| SPECTANO 100 Dielectric Material Analyzer |  |
| Standard accessories:<br>• Triaxial cable<br>• Grounded DRA supply<br>• USB cable |  |
| OMICRON electronics CP TC12 Oil Test Cell (min. 1 liter of sample liquid needed)<br><br>**Note**: Similar three-electrode or dielectric insulation liquid test cells can be used as well. Depending on the material to test we recommend to use test cells with a capacity of 100 ml – 300 ml. |  |
| Triaxial to 4mm banana plug adapter cable set |  |
| Reducer plug 6mm to 4mm (600 V; 32 A) e.g. RS6AR/4S from Multi-Contact |  |

| | |
|---|---|
| 2x safety 4mm plug to plug adapter (1000 V; 32 A) e.g. A-SLK4 from Multi-Contact |  |
| Customized insulation liquid samples<br>**Note:** For this application note a standard mineral oil was used as sample. |  |
| Temperature chamber FD115 from Binder<br>**Note:** For the analysis of insulation fluids it is always important to stabilize the environmental and measurement temperature using a temperature or climate chamber |  |

# 5 Insulation Oil Measurement with the CP TC12 Oil Test Cell

## 5.1 Measurement Setup

**NOTICE**

- Always ground SPECTANO 100 according to the safety rules by using the grounding connector at the rear panel
- Contaminations strongly influence the measurement. For cleaning requirements read the test cell user manual. Always clean dielectric test cells properly prior measurement.
- Bubbles in liquid insulation materials should be avoided. Entrapped air or bubbles influence the measurement significantly.

### 5.1.1 Preparation for Safe Operation

- Before operating SPECTANO 100, ground it as described ground it as described in the SPECTANO 100 user manual.
- Ensure that the ground is in good condition, clean, and free of oxidation.
- Before handling SPECTANO 100 in any way, ground any parts of the test object which have to be connected to ground.
- Always turn off SPECTANO 100 with the power switch before connecting or disconnecting any cables.
- Never remove any cables from SPECTANO 100 or the test object during a test.
- Open a new SPECTANO 100 Analyzer Suite test first. Read and follow the instructions.

### 5.1.2 Hardware Setup

To conduct the measurement, perform the following steps:

1. Fill the insulation liquid sample into the test cell

**NOTICE**

Ensure that the test cell is cleaned and the sample is prepared before filling. For more information about cleaning, preparation and filling a liquid test fixture and sample see

- International standards for dielectric analysis of liquids like ASTM standard D924-08
- Application note **Requirements to perform accurate dielectric material analysis** [2]

[2] All SPECTANO 100 application notes and further video tutorials can be found on the SPECTANO 100 *Knowledge and Applications* area located at https://www.omicron-lab.com/.

2 Connect the 6mm to 4mm reducer plug to the outer electrode connector at the bottom of the CP TC12 oil test cell

Figure 1 Connection of 6mm to 4mm reducer plug to CP TC12 oil test cell

3 Insert the test cell into the temperature or climate chamber
4 Connect the blue and red 4mm banana plug to triaxial plug adapters to the CP TC12 oil test cell
**Hint:** To perform a potential free (floating) measurement for example in case of needs to improve the accuracy, do not connect the ground connectors of both adapter cable ends.
5 Connect the 4mm plug banana adapter cables with the blue and red standard triaxial cable
6 Connect the standard triaxial cables to the SPECTANO 100 OUTPUT and INPUT

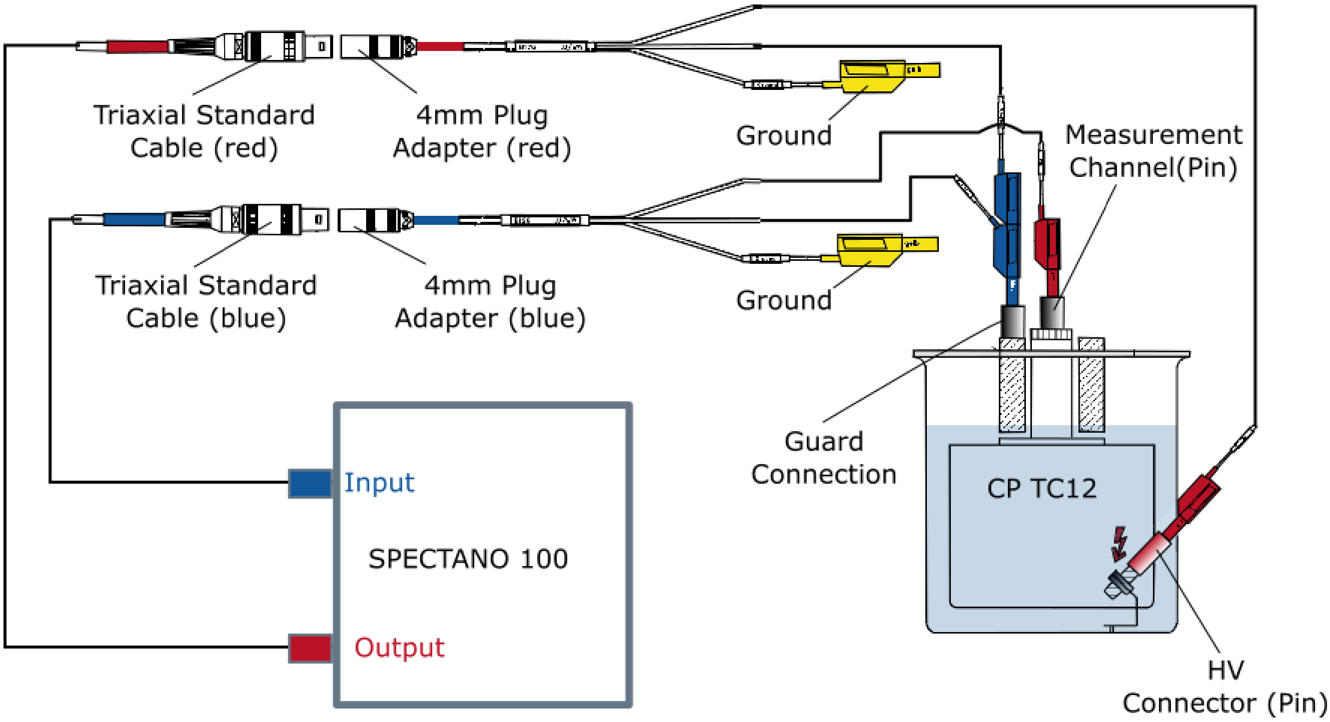



Figure 2 Setup schema using SPECTANO 100 and CP TC 12 oil test cell

7. Connect the power supply connector of the grounded DRA power supply to SPECTANO 100.
8. Connect SPECTANO 100 to a PC using the USB cable.
9. Setup the software (see chapter 5.1.3 )
10. Start the temperature or climate chamber

> **NOTICE**
> Before starting the measurement ensure that the temperature in the chamber, test cell and sample itself is stable. According to international standards like ASTM D924-08 the measurement of dielectric properties may be made when the test sample is within ±2.0 °C of the desired temperature.

11. Start the measurement when the temperature of the test sample is stable

### 5.1.3 Software Setup

Open a new SPECTANO 100 Analyzer Suite test.

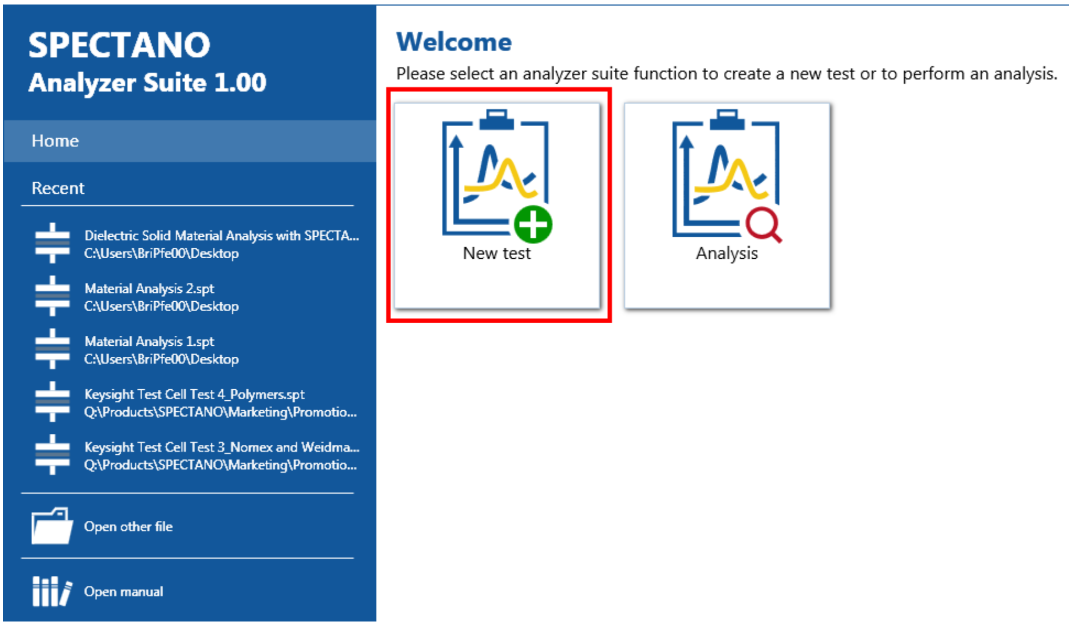



Figure 3: Open new SPECTANO 100 test

To measure the dielectric properties, choose the following setup:

1. Add a measurement for each material, temperature, humidity or measurement voltage you want to analyze.
2. Open the **General test settings** view
3. If you want to perform measurements automatically one after another you can define a waiting time between the measurements.

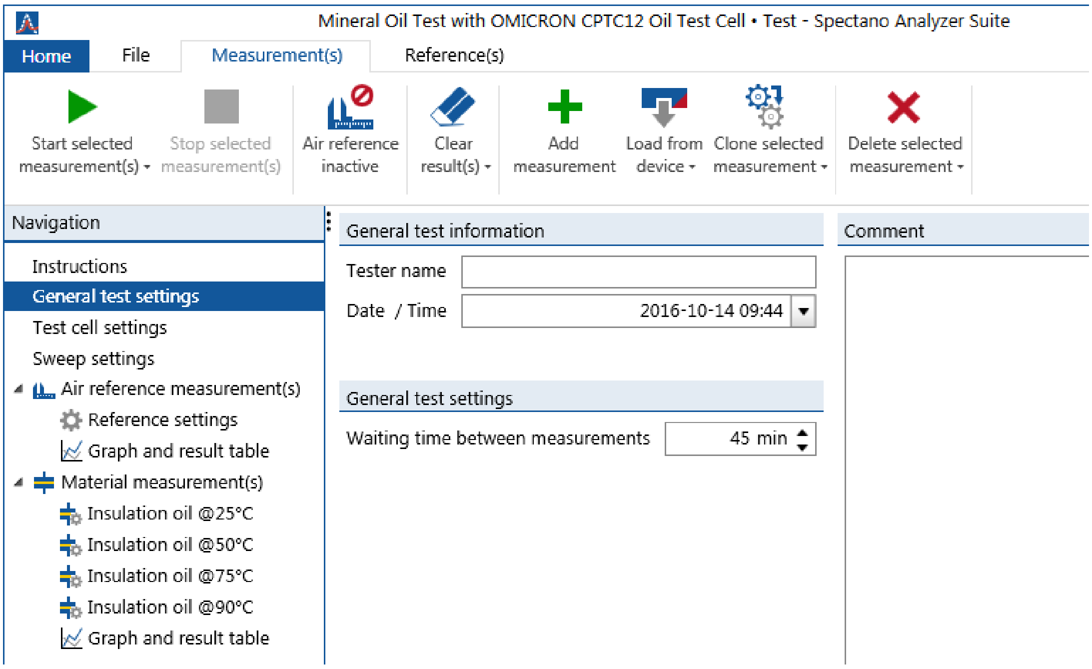



Figure 4: General test settings example for measurement of insulation oil at different temperatures

4 Open the ***Test cell settings*** view.

5 Select the suitable test cell configuration.
The test cell and sample dimensions are needed to calculate the vacuum capacitance $c_0$ which is further on needed to get the relative permittivity of the dielectric material: $\varepsilon_r = \frac{C_r}{c_0}$

**Hint**
The CP TC12 oil sample test cell is not a standard test cell and thus please select ***Others***

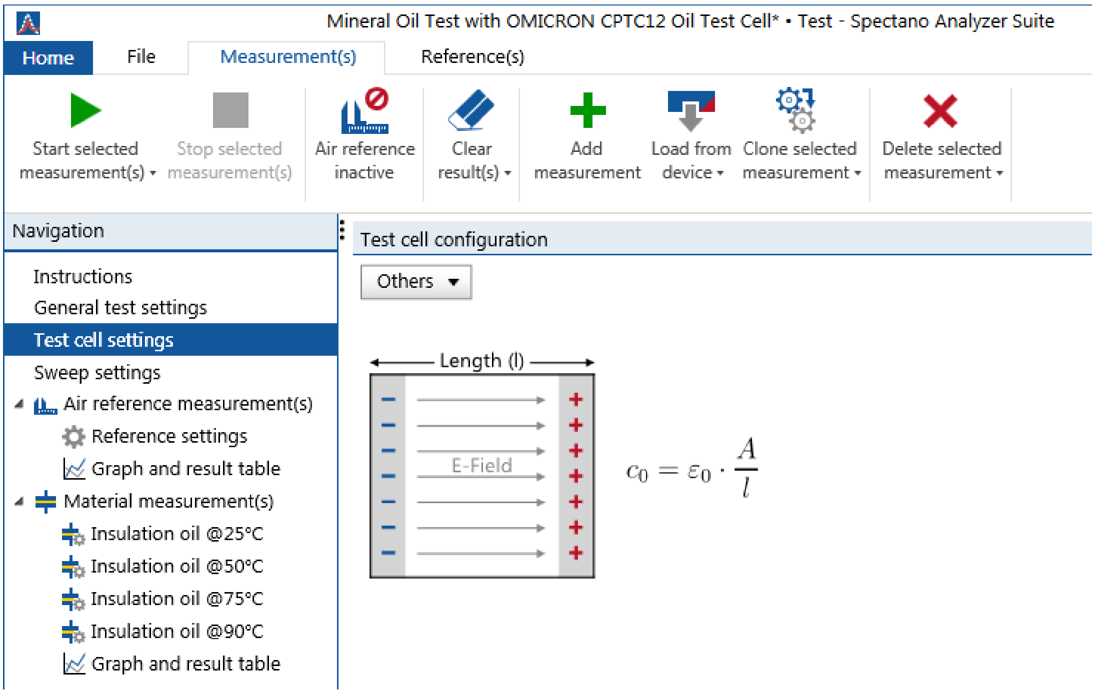



Figure 5: Test cell settings to be selected for CP TC 12 oil sample test cell

6 Open the **Sweep settings** view

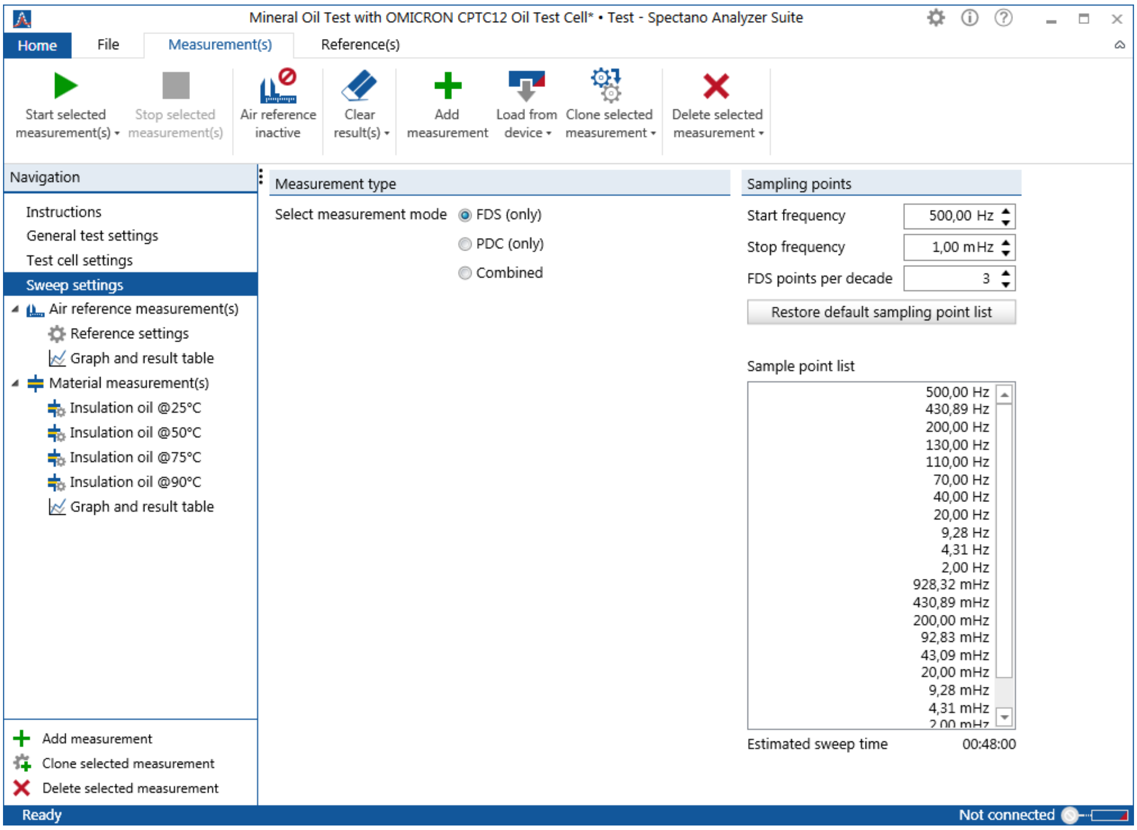



Figure 6: Sweep settings example for measurement of insulation oil at different temperatures

7 Select a measurement mode depending on the material type and test requirements.

**NOTICE**

- The examples described in this document are performed with the **FDS only** (Frequency Domain Spectroscopy) mode. See the SPECTANO 100 user manual or the **Software Functionality** section on our webpage https://www.omicron-lab.com/ for more information on this mode and other available measurement modes.
- Independent from the selected measurement mode always **ensure** that the material is **not pre-polarized before starting** a new measurement.

8 Enter your customized frequency sweep depending on the material type and test requirements

**NOTICE**

The measurements described in this application note are performed with a frequency sweep from 500 Hz to 1 mHz with 3 FDS points per decade.

Reason for frequencies ≤ 500 Hz: To determine the dissipation factor tanδ of an insulation oil sample, it is necessary to select a frequency in the frequency range, where the dissipation factor curve has a constant, non-bent slope.

9 We recommend to perform a reference measurement to eliminate influences of unknown capacitances and to improve the measurement accuracy, especially if the used test cell does not have a guard ring. Please follow the reference measurement instructions in the SPECTANO 100 user manual. Afterwards follow the next step.

10 Open the first **Measurement** view

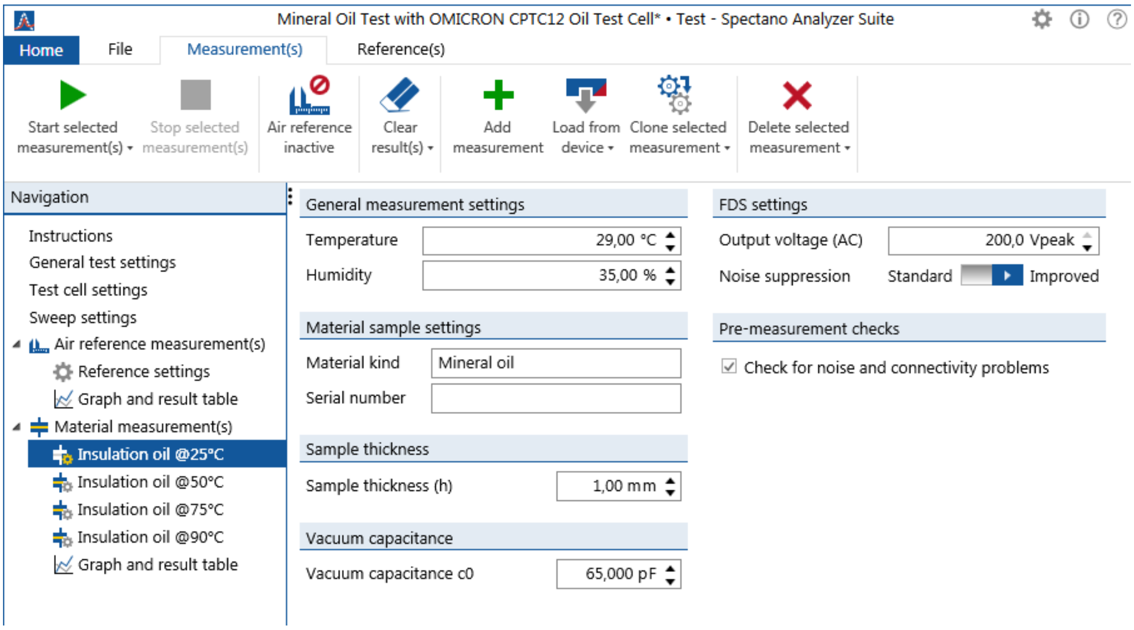



Figure 7: Measurement settings (FDS only mode) example for measurement of insulation oil at different temperatures

11 Apply the following settings for all measurements:

a. Actual temperature equal to the environmental temperature measured beginning of the measurement
b. Actual humidity at the beginning of the measurement
c. Output voltage depending on the material to test and test requirements

**NOTICE**
The measurements described in this application note are performed with 200 $V_{peak}$ (AC).

d. Material type
e. Sample thickness (h) to the thickness of your sample if available
f. Vacuum capacitance $c_0$

**NOTICE**
If **Others** is selected under **Test cell settings,** please calculate the vacuum capacitance $c_0$ manually from your test cell dimension. For the CP TC 12 oil test cell set $c_0$ to 65 pF.

g. Check the pre-measurement checkbox to detect connectivity problems, quality of the measurement signal, overload or pre-polarization of the sample. Depending on the selected measurement mode we recommend to select the following pre-measurement checks:

Table 1: Pre-measurement checks depending on selected measurement mode

| **FDS only** | **PDC only or Combined** |
|---|---|
| Pre-measurement checks<br>☑ Check for noise and connectivity problems | Pre-measurement checks<br>☑ Check for noise and connectivity problems<br>Delay the start of the measurement until...<br>☑ The depolarization current falls below 20,00 pA<br>☐ The time elapsed 120 s |

12 Repeat entering the measurement settings for all other measurements in the list.
You can use the **Clone selected measurement** function to create multiple measurements with the same settings.

13 Depending on the test requirements start a single measurement or measurement sequence after the setup for the hardware and software has been finished and checked:

a. For starting a single measurement select a measurement from the **Start single measurement** list

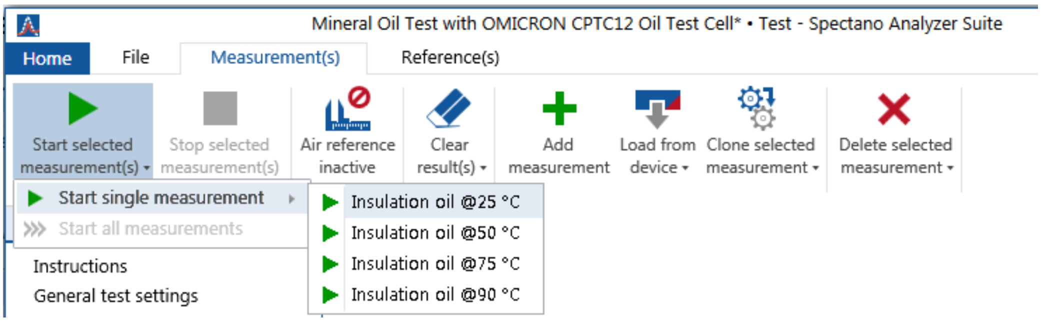



Figure 8: Start single measurement

b. For starting a measurement sequence press the **Start all measurements** button

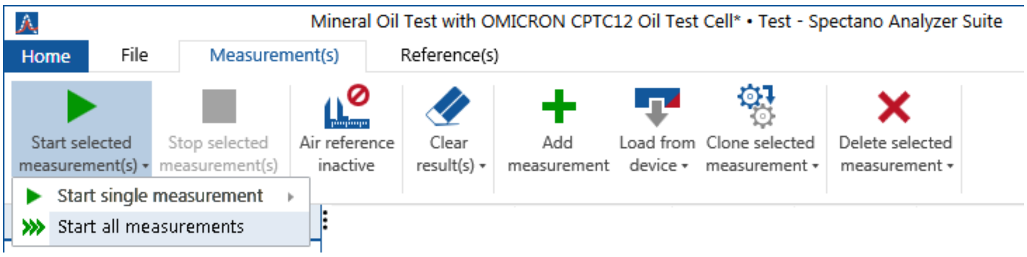



Figure 9: Start measurement sequence

## 5.2 Measurement Results

After the measurement is finished the software will display the tan(δ) curve of the sample. If you are interested in other results, please use open the ***Chart result view*** combo box to switch to switch to another result display mode.

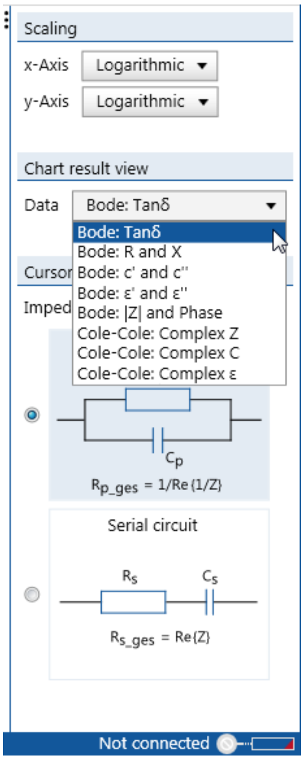



Figure 10: Changing display mode

**NOTICE**

When the **PDC only** or **Combined** measurement mode is selected the polarization and depolarization current results over time can be displayed in addition.

Figure 11 shows the measurement results table. Here you can enter the desired frequency and the according results will be displayed. Alternatively, you can move the cursors in the result diagram.

| | Frequency | Tanδ | ε' | -ε'' | \|Z\| | Phase | Cp | Rp | c' | -c'' | R | -X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Insulation oil @25°C | 2 Hz | 0,0002185 | 2,11E+00 | 4,6E-04 | 581,507 MΩ | -89,987 ° | 136,8471 pF | 2,661 TΩ | 136,8471 pF | 0,0299 pF | 127,054 kΩ | 581,507 MΩ |
| Insulation oil @50°C | 2 Hz | 0,0003393 | 2,09E+00 | 7,1E-04 | 585,322 MΩ | -89,981 ° | 135,955 pF | 1,725 TΩ | 135,955 pF | 0,0461 pF | 198,602 kΩ | 585,322 MΩ |
| Insulation oil @75°C | 2 Hz | 0,0004507 | 2,08E+00 | 9,36E-04 | 589,592 MΩ | -89,974 ° | 134,9704 pF | 1,308 TΩ | 134,9704 pF | 0,0608 pF | 265,729 kΩ | 589,592 MΩ |

Figure 11: Result table view

The screen shots in the following chapters show results for one generic mineral insulation oil sample measured at different temperatures with SPECTANO 100 and the CP TC 12 oil sample test cell using a temperature chamber.

### 5.2.1 Dissipation Factor tanδ Determination

Figure 12 shows the measured tanδ curves of a generic mineral insulation oil at different temperatures (25°C, 50°C, 75°C and 90°C). The dielectric response of an insulation liquid is a straight line with a slope of -20 dB/dec because of the conductive behavior having nearly no polarization effects.

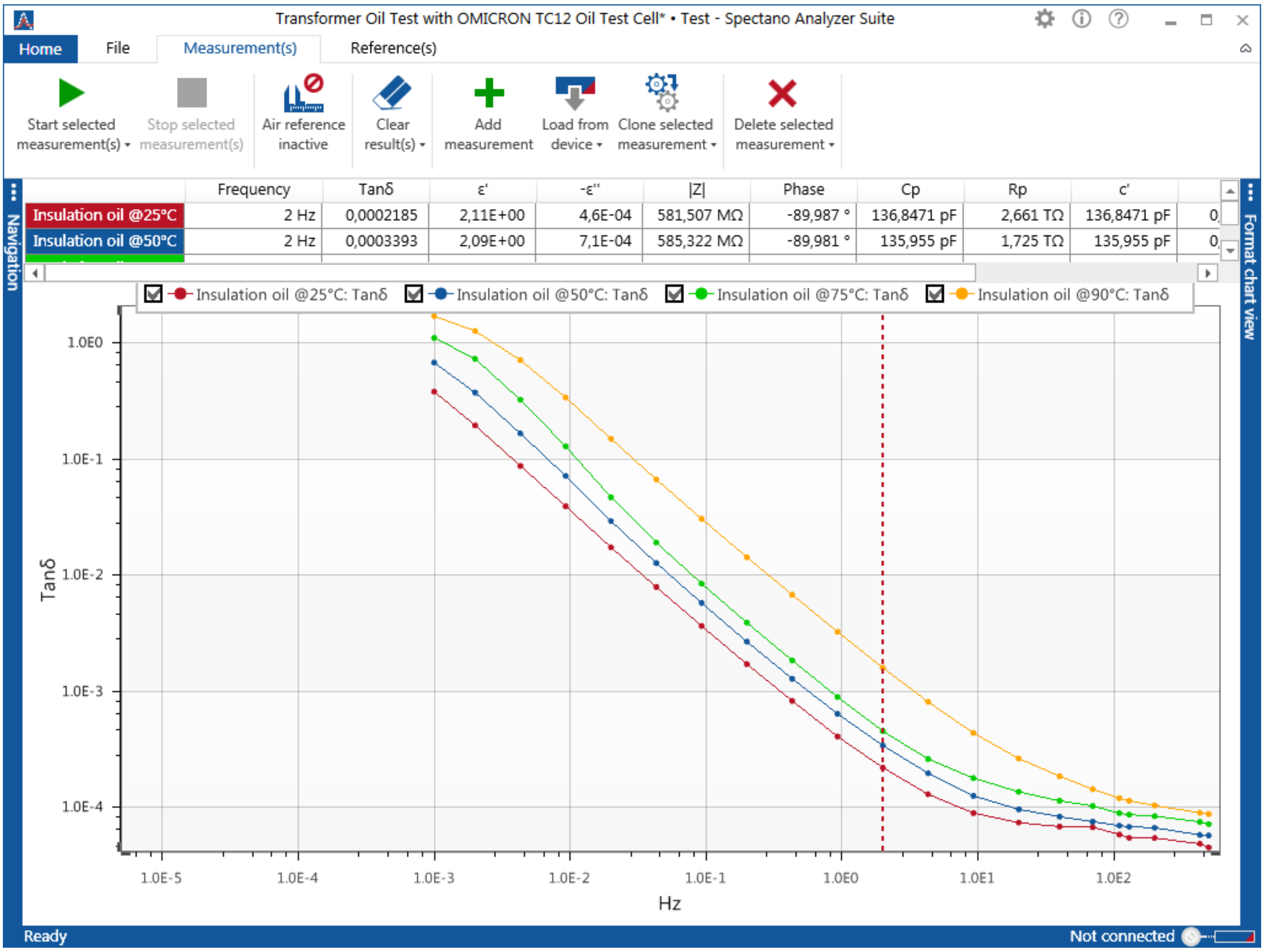


Figure 12: Tan(δ) example curves of mineral insulation oil at different temperatures

To determine the tanδ of an insulation oil or fluid sample, select a frequency in the frequency range of the desired measurement, where the tanδ curve has a constant, non-bent slope.
In Figure 12 this would be around 2 Hz for the mineral oil sample. In that area, the slopes of the curves are straight with about -20dB/dec. In general, the less conductive an insulation liquid is, the more the constant (straight) slope shifts to the right.

**NOTICE**
The frequency range to use for the analysis depends on the material and the test cell.

### 5.2.2 Specific Conductivity Determination

It is possible to calculate the insulation oil or fluid specific conductivity σ(ω) using the tanδ result of the measurement. Formula (1) depicts the calculation.

$$\sigma(\omega) = \varepsilon_r \cdot \varepsilon_0 \cdot \omega \cdot \tan\delta(\omega) \tag{1}$$

| | |
|---|---|
| $\varepsilon_r$ | Relative permittivity |
| $\omega = 2 \cdot \pi \cdot f$ | Angular frequency |
| f | Measurement frequency |
| tanδ (ω) | Loss factor at measurement frequency |
| $\varepsilon_0 \approx 8.8541878176 \cdot 10^{-12} \frac{A \cdot s}{V \cdot m}$ | Permittivity of vacuum |

For the calculation of the specific conductivity use a frequency point which lies on the constant, non-bent slope of the curve.

For example, the mineral oil specific conductivity at different temperatures of the oil sample measurement described in this application note is:

Measurement frequency $f = 40\,mHz$
Angular frequency $\omega = 2 \cdot \pi \cdot f = 0.27\,rad/s$

Table 2: Calculated specific conductivity σ(ω) of mineral oil example measurement @ different temperatures

| Temperature | $\varepsilon_r$ | tanδ | σ(ω) |
|---|---|---|---|
| 25 °C | 2.1049 | 0.00786 | $3.96 \cdot 10^{-14}$ S/m |
| 50 °C | 2.0909 | 0.01266 | $6.35 \cdot 10^{-14}$ S/m |
| 75 °C | 2.0757 | 0.01899 | $9.45 \cdot 10^{-14}$ S/m |
| 90 °C | 2.0562 | 0.06646 | $3.28 \cdot 10^{-13}$ S/m |

The activation energy depends mostly on the medium and is related to the dynamic viscosity. The correlation of the specific conductivity with the temperature of the insulation liquid is based on the fact that a high viscosity and a low temperature result in a higher resistance against the charge carriage of the ions than a low viscosity and a high temperature would. The ions can be considered as spherical charges moving with the electric field in the measuring insulation liquid.

### 5.2.3 Resistivity Determination

The resistivity R(ω) of an insulation oil or fluid can be calculated by using the reciprocal value of the specific conductivity σ(ω). Formula (2) shows the calculation.

$$R(\omega) = \frac{1}{\sigma(\omega)} \tag{2}$$

For example, the mineral oil resistivity at different temperatures of the oil sample measurement described in this application note is:

Table 3: Calculated resistivity R(ω) of mineral oil example measurement @ different temperatures

| Temperature | σ(ω) | R(ω) |
|---|---|---|
| 25 °C | $3.96 \cdot 10^{-14}$ S/m | $2.52 \cdot 10^{13}$ Ωm |
| 50 °C | $6.35 \cdot 10^{-14}$ S/m | $1.58 \cdot 10^{13}$ Ωm |
| 75 °C | $9.45 \cdot 10^{-14}$ S/m | $1.06 \cdot 10^{13}$ Ωm |
| 90 °C | $3.28 \cdot 10^{-13}$ S/m | $0.305 \cdot 10^{13}$ Ωm |

# 6 Summary

The SPECTANO 100 offers all features needed to measure important dielectric parameters such as tanδ, $\varepsilon_r$’ and $\varepsilon_r$”. These parameters can be then used to determine other parameters such as the specific conductivity σ(ω) and resistivity R(ω) of insulation oil or other dielectric liquids.

By using appropriate material samples together with a test cell, SPECTANO 100 and its accessories offer a powerful platform for dielectric analysis of a high variety of liquid insulation materials.

The results obtained with SPECTANO 100 and the TC CP 12 oil sample test cell were reproducible under the same environmental and test conditions. The measured results for the mineral oil (new mineral oil without contaminations) are within the expected value range shown in Table 4:

Table 4: Mineral oil literature relative permittivity values in comparison to measured values

| Temperature | Permittivity literature value at 50 Hz [3] | Measured permittivity value at 50 Hz [4] |
|---|---|---|
| 90 °C | - | 2.06 |
| 80 °C | 2.1 | - |
| 75°C | - | 2.08 |

As can be seen in Table 4 the permittivity values at 50 Hz are the same and changes caused by the temperature or test cell are within the tolerance. Repeated measurements did prove that the results for these materials are reproducible and consistent.

[3] Published: http://www.clippercontrols.com/pages/Dielectric-Constant-Values.html

[4] Measured with SPECTANO 100 and CP TC 12 oil sample test cell

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