SVM 3001 with Abbemat for Transformer Oils

Relevant for: Production of base oils, formulation of transformer and electrical insulation oils. Manufacturers of transformers and power plants for QC

Determine the carbon type composition according to ASTM D2140 and viscosity parameters according to ASTM D3487 and IEC 60296.

1 Why measure viscosity and which other parameters are required for this application?

Transformer oils have two important functions: to be an electric insulator and to act as a coolant for the transformer. Effective cooling will increase the lifetime of the transformer, so the cooling liquid must be able to transfer as much heat as possible.

Viscosity and density at different temperatures are essential for the characterization of insulation oils. The standards IEC 60296 and ASTM D3487 specify such oils at different temperatures. These tests can be performed with the SVM 3001 fast and accurately.

Additionally, the carbon type composition is an important parameter for transformer oils. Critical product performance properties correlate with the carbon type composition. The Standard Practice ASTM D2140 (VGC-r_i method; viscosity gravity constant - refractivity intercept) "Calculating Carbon-Type Composition of Insulating Oils of Petroleum Origin" is used to determine the carbon-type composition of insulating oils.

To calculate the carbon type composition of an oil, the following basic parameters are required:

- kinematic viscosity at 37.78 °C (100 °F) (obtained from SVM 3001)
- refractive index at 20 °C (obtained from the refractometer)
- density at 20 °C (calculated from API functions by the SVM software)
- specific gravity at 15.56 °C (60 °F; calculated by API functions of the SVM software)

For determination of carbon type distribution according to ASTM D2140:

- viscosity-gravity-constant (VGC) according to ASTM D2501, calculated from specific gravity (SG) at 15.56 °C (60 °F) and from kinematic viscosity at 37.78 °C (100 °F)
- refractivity intercept (calculated from refractive index at 20 °C (68 °F) and from density at 20 °C (68 °F)

are required. These parameters are calculated by the SVM 3001 software.

This report describes specifically how to test oils with the SVM 3001 (according to ASTM D7042, D4052 and D2501) in combination with an Anton Paar Abbemat refractometer to get the carbon type composition according to ASTM D2140.

2 Which instruments are used?

For the viscosity and density measurement a manually filled SVM 3001 viscometer is used.

For the RI measurement the Abbemat 550 is used. Connected via CAN interface, it is a module controlled by the SVM 3001 as master instrument.

Tip: Any other Anton Paar refractometer from the Performance/ Performance Plus Line (300/350 or 500) or from the Heavy Duty line (450, 650) can be used.

3 Which samples are tested?

Five oil samples as listed below were tested:

Sample	
Nytro 4000X	Severely hydrotreated insulating oil
T110	Severely hydrotreated base oil
Nyflex 3150	Severely hydrotreated process oil
Nypar 315	Severely hydrotreated process oil
Nytro 10XN	Severely hydrotreated insulating oil

Samples were kindly provided by Nynas AB, Sweden.

4 Sample measurement

4.1 Instrument setup

Carbon type composition

Method: SVM + Abbemat

SVM 3001 (ASTM D7042 measurement)

Following settings are predefined by default:

- Measuring temperature: 37.78 °C
- Precision class "Precise"
- RDV limit 0.10 %
- RDD limit 0.0002 g/cm³
- determinations
- Automatic prewetting: yes
- Sulfur correction: activated (if the oils has a sulfur content of 0.8 % or higher, enter here the value to improve the accuracy of the CTC calculation)
- Drying time: 150 s (built-in air pump)
  when using compressed air at 2 bar: 60 s

Abbemat refractometer:

The method SVM + Abbemat includes the following settings for the refractometer:

- Temperature: 20 °C
- Measurement accuracy "Most Precise"
- Hold time: 1 s
- Timeout: 200 s
- Wavelength: 589.3 nm (fixed parameter)

Low temperature viscosity measurement

These tests can be performed with a temperature scan. Create a method with the settings listed below:

- Measurement mode: Temperature Table Scan
- Measuring temperatures: as required
- Precision class "Precise"
- Equilibration time: 120 s
- Automatic prewetting: yes

Drying time:

- built-in air pump without drying cartridge: 120 s
  Not recommended for drying at cell temperatures below the dew point.
- built-in air pump and drying cartridge: 120 s
  For occasional drying below the dew point.
- compressed air at 0.3 bar with air preparation set dew point -40 °C: 120 s
  For drying below the dew point respectively at low temperatures.

Counter cooling and air preparation equipment:

Measurements down to -20 °C do not require external counter cooling. For better cooling performance, liquid counter cooling can be optionally connected.

For measurements below -20 °C, external liquid counter cooling is required.

If the last temperature of a table scan is higher than the dew point, air drying equipment is not explicitly required. For occasional drying below the dew point a drying cartridge is sufficient. For permanent drying below the dew point or at low temperatures, the air preparation set dew point -40 °C is required.

For low temperature setup and options, consult the SVM X001 Reference Guide and - if applicable - the instruction manual of your counter cooling device.

4.2 Calibration

Use only a calibrated instrument. The calibration shall be performed periodically using certified reference standards. According to ASTM D7042, the reference standards shall be certified by a laboratory, which meets the requirements of ISO/IEC 17025 or a corresponding national standard. Viscosity standards should be traceable to master viscometer procedures. The uncertainty for density standards must not exceed 0.0001 g/cm³. For each certified value the uncertainty should be stated (k = 2; 95 % confidence level). Use one or more standard(s) in the viscosity range of your oil sample(s). If required, apply a calibration correction to improve the reproducibility. To perform the calibration, refer to the SVM X001 Reference Guide.

For the refractometer perform at least a water check. For checks and adjustment of the Abbemat, refer to the documentation of this instrument.

4.3 Sample preparation

If the sample is not freshly drawn from a production line or else, homogenizing the test specimen may improve the measurement repeatability. For some samples degassing may be required. Refer to the SVM X001 Reference Guide.

4.4 Filling

Single-use plastic syringes are sufficient. Never use syringes with rubber sealings, as the rubber is chemically not resistant and these syringes tend to suck bubbles. To have enough sample volume for perfect prewetting and for refills, use a 10 mL syringe.

Ensure that the system (measuring cells and hoses) is leak tight, clean and dry.

For flow-through filling, inject approx. 3.5 mL as first filling. After prewetting refill at least 1 mL or until the sample in the waste hose is free of bubbles. The typical amount for valid results is 6 – 7 mL, where the volume can vary depending on the sample.

4.5 Cleaning

4.5.1 Solvents

Petroleum benzine 100/140 (aliphatic hydrocarbon solvent, blend of mainly C7, C8, C9 *n*-alkanes with a boiling range of 100 °C to 140 °C respectively 212 °F to 284 °F) is a universal solvent, suitable for most oils.

Some oils may require an aromatic solvent, as they are not completely soluble in petroleum benzine. If so, use toluene or xylene as first solvent and an aliphatic hydrocarbon solvent (e.g. *n*-Heptane) as drying solvent.

For cleaning at low temperatures, a final flush with a highly volatile hydrocarbon solvent is recommended.

The typically required solvent volume is 10 – 12 mL per sample.

Avoid using acetone or ethanol, as these solvents are not suitable for most oils.

For details, see the SVM X001 Reference Guide.

4.5.2 Cleaning procedure

Note that the cells of SVM and refractometer operate at different temperatures. This requires more attention to the cleaning procedure.

- Tap the cleaning button to open the cleaning screen. Observe it during the cleaning procedure to get information about the cleaning status of the SVM.
- Remove the sample from the cells (push through using an air-filled syringe).
- Fill approx. 3 mL of solvent using a syringe and leave the syringe connected.
- Tap the motor speed button to improve the cleaning performance in the viscosity cell. The cleaning screen shows the mixing of solvent and sample residue by change of viscosity. The density value indicates whether the cell is filled properly with solvent. Stop the motor again.
- Move the plunger of the syringe back and forth (motor at filling speed) to improve the cleaning performance in the cells of SVM and Abbemat.
- Blow air through the cells for some seconds to remove the sample-solvent-mixture.
- Repeat the procedure until the liquid has reached approximately the solvent's viscosity while the motor is turning at high speed.
- Perform a final flush with a drying solvent to remove any residues.
- Observe the cleaning screen. Dry the measuring cells until the cleaning value turns green and stays steadily green.

For details, see the SVM X001 Reference Guide.

5 Results

For this report, the measurement and calculation results obtained from SVM 3001 and Abbemat 550 and the reference values on the respective data sheets (PDS, CoA) are compared.

Carbon type composition:

Sample	CA [%]	CN [%]	CP [%]
T110	14.50	33.25	52.20
Nypar 315	1.38	30.00	68.60
Nyflex 3150	9.33	30.05	60.65
Nytro 4000X	2.63	44.98	52.40

Table 1: ASTM D2140 (VGC-ri) Carbon Distribution (mean of 4 measurements)

Sample	CA [%]		CN [%]		CP [%]	
	typ.	dev.	typ.	dev.	typ.	dev.
T110	11.7	2.80	38.2	-4.95	50.1	2.10
Nypar 315	1	0.38	34	-4.00	65	3.60
Nyflex 3150	7	2.33	33	-2.95	60	0.65
Nytro 4000X	4	-1.38	45	-0.02	51	1.40

Table 2: Carbon Distribution - Deviation to typical sample values (dev. in percentage points)

Refractive Index:

Sample	RI meas. [nD]	RI typ. [nD]	Dev. [nD]
T110	1.503635	1.502	0.0016
Nypar 315	1.468229	1.468	0.0002
Nyflex 3150	1.495011	1.494	0.0010
Nytro 4000X	1.474635	n.a.	n.a.

Table 3: Refractive Index and deviation to typical values at 20 °C

ASTM D2501 Viscosity-Gravity Constant (VGC):

Sample	result (SVM 3001)	typical (datasheet)	deviation
T110	0.85587	n.a.	
Nypar 315	0.80144	0.804	0.00256
Nyflex 3150	0.83008	0.829	0.00108
Nytro 4000X	0.83852	n.a.	

Table 4: Viscosity-Gravity Constant and deviation to typical values

Kinematic viscosity:

The tables contain viscosity results of two insulating oils meeting the requirements according to the standards ASTM D3487 respectively IED60296 (here stated: Ed. 3). Both oils are specified at -30 °C, where

Nytro 10XN has a stricter low temperature specification for kinematic viscosity given in its data sheet as stated in IEC 60296.

Sample	Temp. [°C]	meas. kin. vis. [mm²/s]	specified max. [mm²/s]	meets range value
Nytro 4000X	100	2.3800	3	OK
	40	9.0995	12	OK
	0	57.048	76	OK
Nytro 10XN	100	2.0684	3	OK
	40	7.5818	12	OK
	0	46.275	76	OK

Table 5: Kinematic viscosity according to specifications in ASTM D3487

Sample	Temp. [°C]	meas. kin. vis. [mm²/s]	specified max. [mm²/s]	meets range value
Nytro 4000X	0	57.255		
	-20	272.45		
	-30	**769.28**	**1800**	**OK**
	-40	2704.7		
Nytro 10XN	0	46.462		
	-20	229.60		
	-30	**687.31**	**800 ***	**OK**
	-40	2669.4		

Table 6: Kinematic viscosity of two insulating oils according to specifications in IEC60296

* Nytro 10XN: max. 800 mm²/s at -30 °C according to its product data sheet.

6 Conclusion

The assembly of SVM 3001 with Abbemat is perfectly suitable for determining the carbon type composition and the low temperature viscosity of insulating oils, provided that all requirements according to section 4, "Sample measurement" are fulfilled.

Figure 1: SVM 3001 with Abbemat 550

7 Literature

- ASTM D7042
- ASTM D2140: Standard Practice for Calculating Carbon-Type Composition of Insulating Oils of Petroleum Origin
- ASTM D2501: Standard Test Method for Calculation of Viscosity-Gravity Constant (VGC) of Petroleum Oils
- ASTM D3487: Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus
- IEC 60296: Fluids for electrotechnical applications - unused mineral insulating oils for transformers and switchgear
- IEC 61868: Mineral insulating oils - Determination of kinematic viscosity at very low temperatures
- Anton Paar Application Report Carbon Type Distribution of Petroleum Oils with SVM 4001 and Abbemat Doc. No. D89IA012EN.

Contact Anton Paar GmbH

Tel: +43 316 257-0

support-visco@anton-paar.com

www.anton-paar.com

APPENDIX

Appendix A. Transformer oils

Most transformer oils are mineral based, they are normally obtained by fractional distillation and following hydrotreatment. There are two main groups: Naphthenic and paraffinic insulation oils.

Further it can be distinguished between inhibited and uninhibited oils. Inhibited oils contain additives, which improve the oil properties, such as pour point depressants, corrosion inhibitors and more.

Naphthenic oils have an excellent low temperature behavior (e.g. low viscosity) while paraffinic types have a higher pour point due to their waxy content. So paraffinic oils need a pour point depressant if they are used at low temperature.

Meanwhile there are also other types of insulating oils available, e.g. synthetic esters or natural esters, but they are not part of this application report.

Carbon type composition

Carbon-type analysis expresses the average amount of carbon atoms which occur in aromatic, naphthenic and paraffinic structures, reporting the percent of the carbon atoms in aromatic ring structures (%C_A), the percent in naphthenic ring structures (%C_N) and the percent in paraffinic chains (%C_P).

There are several physical property correlations for carbon type analysis.

Besides the VGC-r_i method (viscosity gravity constant – refractivity intercept) according to ASTM D2140, a further empirical procedure exists, which comes into use mainly for process oils, the n-d-M method (refractive index – density – mean relative molecular mass), standardized as ASTM D3238. See the AP Application Report "Carbon Type Distribution of Petroleum Oils with SVM 4001 and Abbemat", Doc. No. D89IA012EN, available on the AP Extranet.

ASTM D2140 (VGC-r_i)

“Standard Practice for Calculating Carbon-Type Composition of Insulating Oils of Petroleum Origin”. It is intended for use with fresh oils, inhibited or uninhibited and applies to oils with average molecular weights from 200 to above 600, and 0 to 50 aromatic carbon atoms.

Viscosity, density, relative density (specific gravity) and refractive index are the only experimental data required for use of this method. From these measured properties the viscosity-gravity constant (VGC) and refractivity intercept (r_i) are obtained by calculation.

Viscosity Gravity Constant (VGC)

The viscosity-gravity constant is a useful function for the approximate characterization of the viscous fractions of petroleum. It is relatively insensitive to molecular weight. Values of VGC near 0.8 indicate samples of paraffinic character, values close to 1.0 indicate a preponderance of aromatic structures.

The VGC is calculated from specific gravity and kinematic viscosity.

Mineral oils are classified as follows:

Mineral oil	VGC
Paraffinic mineral oil:	0.790 – 0.819
Slightly naphthenic mineral oil:	0.820 – 0.849
Naphtenic mineral oil:	0.850 – 0.899
Slightly aromatic mineral oil:	0.900 – 0.939
Aromatic mineral oil:	0.940 – 0.999
Highly aromatic mineral oil:	1.000 – 1.049

Table 7: VGC of mineral oils

Refractivity Intercept (r_i)

From the measured density and refractive index, the refractivity intercept is calculated according to the formulae in ASTM D2140 (respectively according to ASTM D2159). The calculated values of VGC and ri are used with the nomogram below, to correlate those parameters with carbon-type composition.

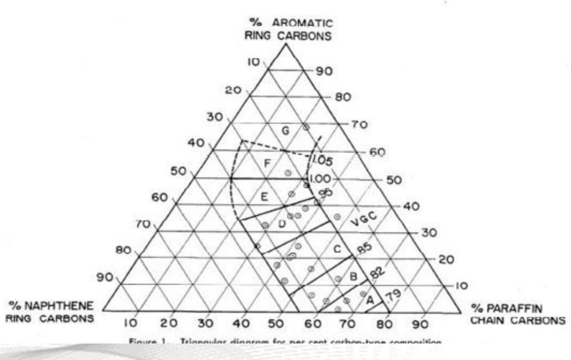

Figure 2: Carbon type composition

"SVM + Abbemat" Method

This fast and accurate method provides mainly the basic parameters and the analysis result for carbon type composition according to ASTM D2140.

If additional, useful parameters for oil characterization are required, SVM 3001 provides a further method "Viscosity Index + Abbemat".

Besides measurement of the required basic parameters for calculation, this method offers e.g.:

- Kinematic viscosity at 40 °C and 100 °C (extrapolated according to ASTM D341)
- Viscosity Index (according to ASTM D2270)
- Carbon type distribution and ring content according to ASTM D3238
- Mean molecular mass following ASTM D2502
- Density 20 °C
- API Spec. Gravity 15.56 °C (60 °F)

The "Viscosity Index + Abbemat" method is a temperature scan method.

For further tests on viscosity behavior of an oil, also a time scan mode is available.

Viscosity

Transformer oils act as coolant and insulation oil. Besides other properties, viscosity is a main parameter influencing the heat transfer and therefore the temperature rise within the transformer. The lower the viscosity, the easier the oil can circulate which improves heat transfer. Depending on the cooling system of the transformer, higher viscosity at low temperatures is a critical factor for the cold start of a transformer, especially for models with natural oil circulation. No or bad circulation can lead to overheating at the hot spots and it unfavorably influences the speed of moving parts, such as in pumps or power circuit breakers.

Generally, oils with a higher content of naphthenic molecules will decrease their viscosity faster than oils with a high content of paraffinic structures. Naphthenic oils have also a better heat transfer coefficient than paraffinic oils with similar viscosity at 40 °C. Additionally, naphthenic oils provide excellent low temperature behavior as they have a significantly lower pour point compared to paraffinic types. This improves the pumpability of the cold oil and allows starting a transformer at the lowest possible temperature.

Producers of such oils state in their product data sheets besides other parameters also kinematic viscosity at different temperatures (which must meet specifications according to several standards) and often the Viscosity Index as an indicator for the viscosity-temperature behavior of the oil.

Viscosity limits are defined in ASTM D3487 and IEC 60296 (here stated: Ed. 3):

Property requirements (excerpt: viscosity) for transformer oil types I and II according to ASTM D3487:

Temp [°C]	Kinematic viscosity, max. [mm²/s; cSt]	
	Type I	Type II
100	3.0	3.0
40	12.0	12.0
0	76.0	76.0

Table 8: Maximum kinematic viscosity (ASTM D3487)

Maximum kinematic viscosity and pour point of transformer oil at the lowest cold start energizing temperature (LCSET) according to IEC 60296:

LCSET [°C]	Max. viscosity [mm²/s; cSt]	Max. pour point [°C]
0	1800	-10
-20	1800	-30
-30 *	**1800**	**-40**
-40 **	2500	-50

Table 9: Maximum kinematic viscosity and pour point (IEC 60296)

* Standard LCSET for low temperature transformer oils. Can be modified according to the requirements due to the climate in the respective country. The pour point always should be at least 10 K below LCSET.

** Standard LCSET for low temperature switchgear oil. The kinematic viscosity should not exceed 400 mm²/s at the LCSET.