Viscosity Index of Base and Lube Oils with SVM 4001

Refineries, lube oil blenders, lubricant R&D, bulk consumers (manufacturers of land-, water- and aircrafts, engines and machinery for incoming QC)

Base oils are the main ingredient of formulated lube oils. Lubricating oils are used in various industries and must fulfill different requirements. Kinematic viscosity and the Viscosity Index are the most important parameters for both base and lube oils. The Anton Paar SVM 4001 is a perfect solution for viscosity measurement at two temperatures and VI calculation.

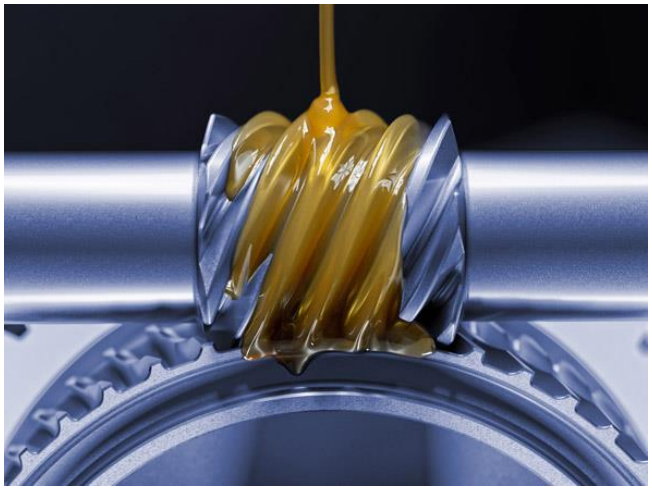

Figure 1: Formulated lube oil

1 Why measure viscosity and determine the VI?

Kinematic viscosity at 40 and 100 °C is the input parameter for calculation of the Viscosity Index (VI) according to ASTM D2270.

The VI shows the influence of temperature on an oil‘s viscosity and is an important parameter for the oil’s lubrication properties.

Low VI means the viscosity changes considerably at different temperatures. Such oil is highly viscous at low temperatures and rather liquid at high temperatures. A high VI means the opposite: the viscosity changes only slightly at different temperatures over a wide temperature range.

This report describes how to measure base oils and lube oils at 40 and 100 °C simultaneously from one syringe. The Viscosity Index is automatically calculated from these results.

2 Which instrument is used?

For these tests, SVM 4001 is the best solution. SVM 4001 features two integrated viscosity and density measuring cells which are filled in one go. The lower cell is set to 40 °C, the upper one to 100 °C.

Besides the measurement at these two temperatures, viscosity measurement can also be performed at other temperatures within the measuring range (e.g. at 50 °C and 80 °C) if required. The instrument software calculates the required viscosity values at 40 and 100 °C from the obtained results according to ASTM D341 and Viscosity Index is automatically calculated.

Due to the integrated density oscillators of the SVM 4001, the density measurement according to ASTM D4052 or ISO 12185 is carried out simultaneously with the viscosity measurement. Moreover, API calculations of density over temperature are integrated in the instrument software and are freely selectable on the 10.4” touch-screen.

Users can choose from four different precision classes depending on the sample and the precision requirement, which also impacts the duration of the measurement.

3 Which samples are tested?

Five base oils from ASTM PTP and three ready-to-use commercially available formulated lube oils are tested.

Base oils	Formulated lube oils
BO1412	Engine oil 10 W40
BO1408	Gear oil 75W140
BO1404	Automatic Transmission Fluid
BO1312	
BO1212	

Table 1: Tested samples

4 Measuring the samples

4.1 Instrument settings

Measurements according to ASTM D7042.

- Method: SVM 4001 VI
- Measurement mode: Repeated
- Precision class: Precise
- RDV: 0.10 %
- RDD: 0.0002 g/cm³
- Automatic prewetting: yes

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.

4.3 Sample preparation

If the sample is not freshly drawn from a production line or elsewhere, homogenizing the test specimen might improve the measurement repeatability. Proceed as follows: Fill approx. 100 mL of sample into a glass beaker, cover it with a laboratory film to avoid contamination and stir the sample on a magnetic stirrer at low speed for approx. 5 min.

4.4 Filling

Single-use syringes with a volume of 10 mL are recommended to have enough sample for refills. Never use syringes with a rubber sealing, as the rubber is chemically not resistant and also these syringes tend to draw bubbles.

Ensure that the measuring cells are leak tight, clean and dry.

Fill approx. 2.5 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 sample quantity is 6 to 8 mL (including prewetting and refills), 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 for cleaning over a wide temperature range. Ensure that the solvent starts boiling at a temperature higher than the measuring temperature. Otherwise a lack of cleaning in the hot upper cell may impact the measuring results.

The typically required solvent volume is 9 to 12 mL per sample.

In any case, the used solvent needs to dry up completely at the measuring temperature. If using a single solvent, the solvent quality shall be "chemically pure“ or "for synthesis“. If using two solvents, only the second solvent needs to meet this quality.

Some oil samples require an aromatic solvent like toluene or xylene, as they are not (completely) soluble in petroleum benzine. In this case, use the aromatic solvent first, the aliphatic hydrocarbon solvent as the second one.

Avoid using acetone or ethanol, as these solvents start boiling below the temperature of the upper cell.

4.5.2 Cleaning Procedure

- Tap the cleaning button to open the cleaning screen. Observe it during the cleaning procedure.
- 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 both in the density oscillator and in the viscosity cell.
- Blow air for some seconds through the cells to remove the sample-solvent-mixture.
- Repeat the procedure until the liquid has reached approx. the solvent’s viscosity while the motor is turning on 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 both cells.

For details, please refer to the SVM X001 Instruction Manual.

5 Results

For all tested samples, repeat measurements were performed according to ASTM D7042. Based on the valid results (n = 11), the mean value and standard deviation is calculated and displayed in the tables below. Looking at the standard deviation, all samples showed a good repeatability.

5.1 Base oils

The results were compared to the robust mean of the ASTM PTP (Proficiency Testing Program) results obtained by ASTM D445.

The absolute deviation between the SVM 3001 results and the ASTM PTP results were within the measurement uncertainty of SVM of ±0.35 %.

40 °C:

Sample	ASTM D7042 Kin.vis [mm²/s] (measured)	ASTM D445 Kin.vis [mm²/s] (reference)	Dev. to D445 %	Std. dev. r (2 σ) %
BO1412	20.814	20.84	-0.124	0.043
BO1408	38.240	38.26	0.053	0.025
BO1404	99.857	99.81	0.047	0.021
BO1312	21.253	21.30	-0.221	0.016
BO1212	28.215	28.23	-0.053	0.022

Table 2: Kinematic viscosity of base oils at 40 °C

100 °C:

Sample	ASTM D7042 Kin.vis [mm²/s] (measured)	ASTM D445 Kin.vis [mm²/s] (reference)	Dev. to D445 %	Std. dev. r (2 σ) %
BO1412	4.1420	4.152	-0.237	0.044
BO1408	6.0974	6.110	-0.206	0.038
BO1404	11.344	11.364	-0.178	0.031
BO1312	4.5138	4.512	0.040	0.012
BO1212	5.1573	5.169	0.033	0.008

Table 3: Kinematic viscosity of base oils at 100 °C

Viscosity Index (ASTM D2270):

Sample	Viscosity Index (determined)
BO1412	98.57
BO1408	104.23
BO1404	99.59
BO1312	127.84
BO1212	113.36

Table 4: Viscosity Index of base oils

Generally, most base oils have a rather low VI compared to formulated end products. The higher the temperature related change of viscosity, the lower the VI is. Depending on the group of base oils an oil belongs to, there are also differences.

For example, BO1412 and BO1312 have a similar kinematic viscosity at 40 °C.
At 100 °C, the kinematic viscosity of BO1312 is approx. 9 % higher than the viscosity of BO1412. The oils show a similar temperature dependent behavior. But the VI of BO1312 is approx. 30 % higher than the VI of BO1412. Considering the VI, BO1412 can be a group I or II base oil (VI 80 to 120), while BO1312 can be a group III or IV base oil (VI > 120).

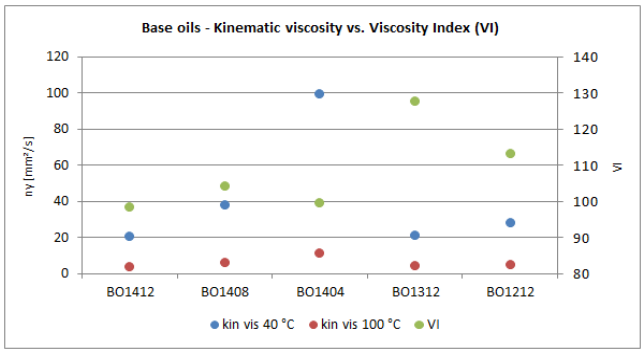

Figure 2: Kinematic viscosity and VI of base oils

5.2 Formulated lube oils

The results are compared to the data given on the product data sheets of the oils. These are typical values stated by the oil blending company and can vary slightly depending on the oil batch. Usually, the PDS values are obtained by ASTM D445 measurements.

40 °C:

Sample	ASTM D7042 Kin.vis [mm²/s] (measured)	Typical Kin.vis [mm²/s (data sheet)]	Dev. to Typical %	Std. dev. r (2 σ) %
Eng.Oil 10W40	96.09	99	-2.94	0.012
ATF	38.80	38	2.10	0.023
GearOil 75W140	174.00	175	-0.57	0.035

Table 5: Kinematic viscosity of formulated lube oils at 40 °C

100 °C:

Sample	ASTM D7042 Kin.vis [mm²/s] (measured)	Typical Kin.vis [mm²/s] (data sheet)	Dev. to Typical %	Std. dev. r (2 σ) %
Eng.Oil 10W40	13.979	14.2	-1.55	0.059
ATF	7.6349	7.5	1.80	0.047
GearOil 75W140	24.513	24.7	-0.76	0.114

Table 6: Kinematic viscosity of formulated lube oils at 100 °C

Viscosity Index (ASTM D2270):

Sample	Viscosity Index (determined)	VI typical (data sheet)	Dev. to typical value %
Eng.Oil 10W40	148.46	148	0.31
ATF	169.84	170	-0.10
GearOil 75W140	172.79	174	-0.69

Table 7: Kinematic viscosity of formulated lube oils at 40 °C

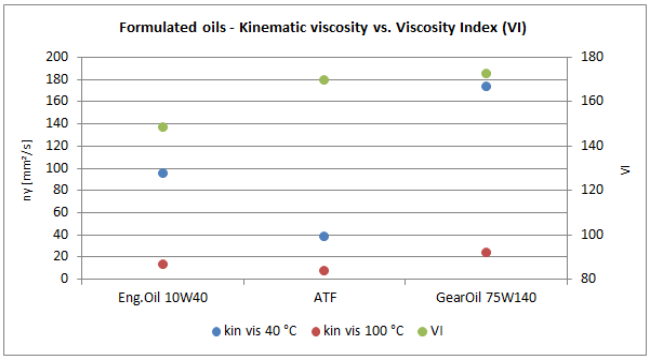

Figure 3: Kinematic viscosity and VI of formulated oils

Ready to use formulated lube oils contain various additives to trim the oils properties perfectly for its later application. VI improvers (these are mainly polymers with different temperature depending properties) are a main ingredient of formulated oils. They keep the temperature related viscosity change as low as required and shift therefore the Viscosity Index, as shown in Fig. 4.

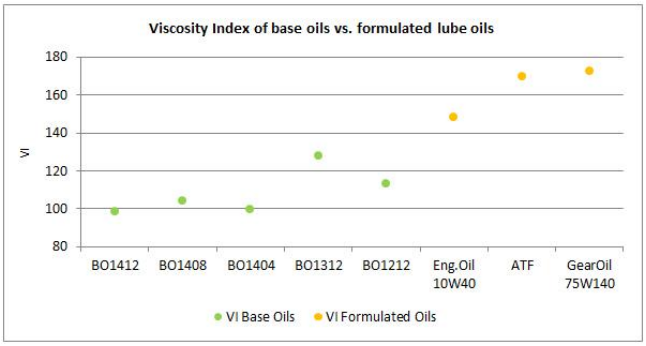

Figure 4: Comparison VI of base oils vs. formulated oils

Specifications according to SAE:

Automotive engine oils measured according to ASTM D7042 are within the specifications of SAE J300, gear oils within those of SAE J306.

For automatic transmission fluids, SAE J311 specifies several parameters, but ATFs must mainly fulfill manufacturer (OEMs) specifications.

SAE specifications at 100 °C:

Sample	ASTM D7042 Kin.vis [mm²/s] (measured)	SAE J300 Kin. Vis. (specified)	SAE J306 Kin. Vis. (specified)	Fulfilled
Eng.Oil 10W40	13.979	12.5 to 16.3	n.a.	yes
GearOil 75W140	24.513	n.a.	24 to 32.5	yes

Table 8: Kinematic viscosity of formulated oils compared to SAE specifications

6 Conclusion

SVM 4001 is perfectly suited for determining the kinematic viscosity and calculating the Viscosity Index. Please ensure that equipment and settings are in accordance with this report (see section 4, ”Measuring the samples”). Viscosity results are obtained according to ASTM D7042. They show excellent repeatability and are within the specification limits for ASTM D445 results.

Figure 5: SVM 4001 – Best solution for VI measurement

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