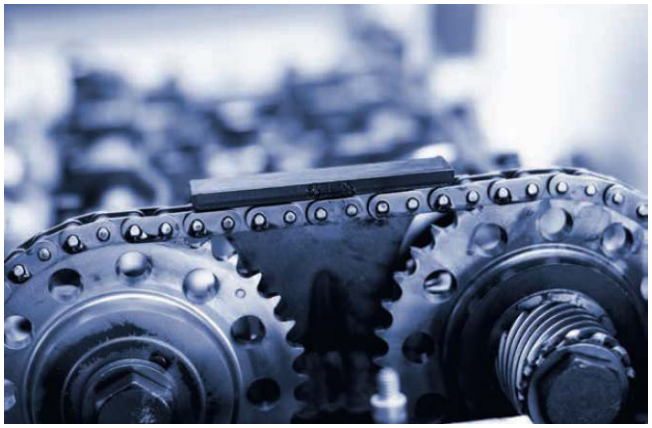
When Is the Right Time for an Oil Change? – SVM Tells Us!

Relevant for: used oil analysis labs, transport companies, operating companies of industrial or construction machinery, wind power plants, lube R&D ...

The Anton Paar SVM viscometer series allows for fast and reliable monitoring of the quality of in-service oil. One filling is enough for precise determination of both kinematic and dynamic viscosity and additional calculation of the Viscosity Index (VI). Metal measuring cells, independence of thermostat baths, and compact design make SVM the ideal tool for testing oils that are in use.



1 Why measure viscosity

Viscosity is a key parameter in determining the quality of lubricating oil. Used oil clearly shows a lower VI (Viscosity Index) and different viscosity than a fresh one of the same type. The lower the VI, the more the oil is influenced by temperature changes. Therefore, a lube oil's viscosity and/or VI are more reliable indicators for the condition of the lube oil than mileage or time of use. It is essential to determine the following parameters:

- Kinematic viscosity at +100 °C
- Kinematic viscosity at +40 °C,
- Viscosity Index (VI), calculated from the both above values

In addition, used oil analysis includes various other parameters to be tested.

Regular oil checks on machinery help to keep the equipment working and to save money by using the oil for the longest possible service lifetime.

Anton Paar provides the SVM x001 for viscosity measurement according to DIN 51659-2 and to ASTM D7042, respectively. It is an excellent alternative to conventional capillary viscometry for fast and economical measurement of the low-shear kinematic viscosity over a wide temperature range.

The internal software is able to calculate the VI from usual viscosity values at 40 °C and 100 °C and from other temperatures according to ASTM D341. In addition, SVM can provide several other parameters, e.g.

- API density at different temperatures, ,
- API specific gravity,
- API number,
- Saybolt viscosity,

and many more.

2 Samples

For this report, six different in-service oils were tested.

Samples	Sample type
ISDO 1307 ISDO 1407 ISDO 1211 ISDO 1203	In-service diesel engine oils from ASTM proficiency testing program
In-serv. oil No. 1 *	Oil with 600 hours of runtime from an engine testing bench
In-serv. oil No. 2 *	Oil from a round robin

* In-serv. oils No. 1 and 2 were generously provided by AVL List GmbH, Graz, Austria.

3 Instrumentation

For this report, the used oil samples were measured with a manually filled SVM 3001 with magnetic particle trap.

Tip: The SVM series also comprises SVM 4001 and SVM 2001. Depending on requirements, either of these models can be used alternatively.

3.1 Magnetic Particle Trap (MPT)

This accessory is essential when measuring in-service oils. Such samples generally contain ferromagnetic particles abraded from the machine. Those particles would settle on the magnetic inner rotor of SVM and cause faulty measuring results. A large amount of particles could even block the rotor.

The MPT is electrically heated (approximately 80 °C). The high temperature decreases the sample viscosity during filling and optimizes the removal of ferromagnetic particles from the sample. The device is easy to use and clean.

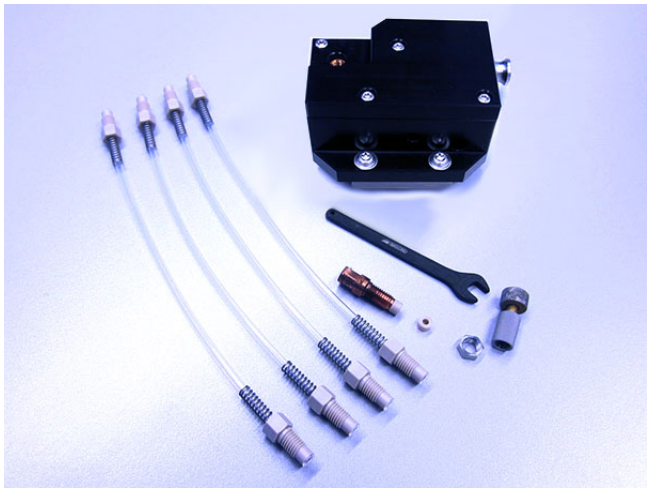


Figure 1: Parts of Magnetic Particle Trap for SVM

3.2 Installation

To install and set up the instrument with MPT and further accessories refer to the SVM x001 Reference Guide.

Find optional accessories in the SVM x001 Product Description List.

4 Measurement of in-service oil

4.1 Preparing the sample for measurement

Sample preparation of used oils depends on the source of the oil. Perform only the minimum required sample preparation required for measurement, as every step influences viscosity and density. After preparation, measure the sample immediately to avoid possible separation.

4.1.1 Homogenizing samples

In-service oils are often inhomogeneous, especially if not measuring them immediately after they were drawn. Homogenize them as follows in order to improve the measurement repeatability:

Stir the sample in its original container e.g. on a magnetic laboratory stirrer at low speed (to avoid bubbles) for approximately 5 to 10 minutes. Then take the test specimen and measure it immediately.

4.1.2 Samples containing large swarfs and other solid contaminants

Remove solid matter (e.g. metal swarfs or solid combustion residues) if required. ASTM D7042 (and ASTM D445) recommend to remove particles larger than 75 µm. The maximum tolerable particle size from technical reasons is 200 µm. If required, filter the oil using a sieve or filter. Following mesh sizes listed in Table 1 can be used in the range between 75 and 200 µm.

Mesh size	Particle size in microns	Mesh size	Particle size in microns
80	177	140	105
100	149	170	88
120	125	200	74

Table 1: Mesh sizes and corresponding particle sizes in µm

Note: Remove only particles, which are larger than the maximum allowed size. Removing more particles than necessary would falsify the measurement results.

4.1.3 Handling gassing samples

Used oil can contain cooling liquid, condensed water or can be diluted by unburnt fuel. In most cases, that is the reason for invalid results at 100 °C even in a low precision class: both, water and fuel, are gassing. If possible, the contaminants should not be removed (e.g. by boiling the sample) as this would change the measurement results.

Measuring at a lower temperature

To get results also with such samples, the measurement can be performed at a lower temperature than 100 °C. The SVM software can then extrapolate resulting values to 100 °C or other relevant temperatures. Viscosity is calculated according to ASTM D341, density by linear extrapolation according to ASTM D7042.

Choose a suitable measurement mode (e.g. Viscosity Index mode), as extrapolation/interpolation requires values at two different temperatures. The minimum required difference between the two temperatures is 20 °C.

Measuring under counter pressure

In many cases it can be helpful just to keep the waste hose closed during measurement to suppress gassing. For this case, a stop cock can be used. See the SVM x001 Product Description List.

Alternatively, the sample can be measured by applying counter pressure using the optional pressurized waste bottle. As SVM 3001 cannot operate the air pump during measurement, an external compressed air supply, safely limited to 1 bar, is required. See the SVM x001 Reference Guide.

Measuring under pressure impacts the results. Density and viscosity readings rise by approx. 1 % per bar

4.2 Settings

Repeated determinations at one temperature:

- SVM 3001, according to DIN 51659-2
- Method: Standard
- Precision class "Fast"
- RDV limit 0.50 %
- RDD limit 0.0005 g/cm³
- 5 determinations
- Automatic prewetting: yes
- Drying time (built-in air pump):
  – at 40 °C: 80 s
  – at 100 °C: 60 s

Automatic Viscosity Index measurement:

SVM 3001

- Method: Viscosity Index
- Precision class "Precise"
- RDV limit 0.10 %
- RDD limit 0.0002 g/cm³
- Automatic prewetting: yes
- Drying time (built-in air pump):
  same as for single point measurement

Note: SVM 3001 does not measure repeated determinations in the VI mode. It performs only one single determination at each temperature.
ASTM D2270 requires repeated measurements at each temperature. For VI determination according to ASTM D2270, use the double-cell viscometer SVM 4001 (separate application report available).

For SVM 2001, a VI mode is optionally available.

Rapid, single point determinations at one temperature

These settings provide fast results but low precision. Filling and measuring times are reduced to a minimum. In this case, SVM x001 cannot fulfill the requirements of ASTM D7042. Such fast results may be sufficient to see a tendency of the tested oil or if a higher throughput is required and low precision is accepted.

- Method: Standard
- Precision class "Ultrafast"
- Automatic repetitions: 0
- Automatic prewetting: no
- Drying time (compressed air supply, 1 bar):
  25 s

4.3 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 sample(s). If required, apply a calibration correction to improve the reproducibility. To perform the calibration and to apply a correction, refer to the SVM x001 Reference Guide.

4.4 Filling

Use PE/PP single-use syringes. Never use syringes with rubber sealings, as the rubber is chemically not resistant and these syringes tend to suck bubbles.

- Ensure that the magnetic particle trap is connected to the power supply and that the trap has reached operating temperature.
- Attach the syringe with the prepared sample to the Luer/UNF adapter on the magnetic particle trap.
- Fill approx. 2.5 mL sample slowly via the MPT into the measuring cells. A slow sample flow improves the removal of ferromagnetic particles. Sample volume: typically 5 mL (depending on sample)

4.5 Cleaning

4.5.1 Solvents

There are mainly two options for sufficient cleaning.

Using two solvents:

Recommended for heavily contaminated oils.

- 1 prewashing solvent to remove particles
- 1 solvent for cleaning and drying the cells

1. Prewash for particles:

Use a rather viscous liquid such as

- Diesel fuel / kerosene or
- a low-viscosity oil (approximate viscosity ISO VG2)

This liquid acts as a carrier substance for solid contaminants like soot and other particles. A typical very low-viscosity solvent would remove the oily component and leave soot residues and other contaminants on the measuring surface.

Over time, a layer of residue would build up. For prewashing liquids any cheap quality is sufficient.

2. Cleaning and drying:

Petroleum benzine (a dearomatized hydrocarbon solvent, blend of mainly C7, C8, C9 n-alkanes) with a boiling range of 100 °C to 140 °C is the best choice. This universal solvent can be used up to 100 °C.

Alternatively, a mixture of toluene and isopropyl alcohol (50-50 % v/v) or the ternary solvent mixture as described below can be used.

The solvent quality shall be "chemically pure“ or "for synthesis“.

Note: Do not use ethanol or acetone as drying solvent. These solvents have a negative influence on the surface wetting behavior for oils. The filling quality of the measuring cells is worse compared to after using hydrocarbon solvents.

Using a ternary solvent mixture:

For samples, which contain a lot of different contaminants, a ternary solvent mixture consisting of toluene, isopropyl alcohol and petroleum benzine (100-140) in the ratio 40-30-30 % (% v/v) is effective, as it contains aromatic, aliphatic and alcoholic components. This mixture applies also perfectly as drying solvent after a prewash liquid for heavily contaminated oil.

4.5.2 Cleaning procedure

For details, see the SVM x001 Reference Guide.

To avoid sample spills when disconnecting the MPT hose from the measuring cells, remove the sample either with an air filled syringe or suck it back into the used syringe.

Cleaning the MPT:

- Disconnect the MPT hose from the measuring cell and connect it to the waste container.
- Pull out the switch on the MPT rear side and rinse the MPT with prewash solvent until it becomes clean (use a syringe).
- Flush the MPT with drying solvent.
- Switch on the air pump and dry the MPT.

Cleaning the measuring cells:

Tip: Open the cleaning screen. Observe it during the cleaning procedure. It gives helpful information on the cleaning and drying status of the cells.

- Fill approximately 2 mL of prewash solvent using a syringe. The syringe remains connected.
- Start the motor for a few seconds to improve the cleaning performance in the viscosity cell.
- Move the plunger of the syringe forth and back when the motor is at filling speed. This improves the cleaning performance both in the density oscillator and in the viscosity cell.
- To avoid spilling, suck the liquid from the cells back into the syringe.
- Repeat the above steps at least once.
- Perform the same procedure with drying solvent until the liquid from the cells is clean.
- Perform a final flush with fresh solvent to remove any residues. If applicable, flush with a second solvent to improve the drying.
- Allow a sufficiently long drying time to be sure that the solvent can dry up completely.

Solvent consumption: typically 10 mL
(depends on type and contamination of the oil)

5 Results

The results were obtained with an SVM 3001 using the standard full range adjustment. No calibration correction was applied.

5.1 ASTM ISDO (In Service Diesel engine Oil)

This first part of the results section compares the data of in-service diesel engine oil measured at 40 °C and 100 °C with SVM 3001 (ASTM D7042) and CFO reverse flow viscometer (ASTM D445). Additionally, the SVM 3001 results are compared to those obtained by Houillon viscometer (ASTM D7279).

In-service oil	SVM 3001 D7042 mm²/s	D445 mm²/s	D7279 mm²/s	R (D445) %	R (D7279) %	deviation D7042 to D445 %	deviation D7042 to D7279 %
ISDO 1307	124.03	124.70	125.25	0.960	5.216	-0.54	-0.98
ISDO 1407	65.433	65.590	65.261	1.044	1.263	-0.24	0.26
IDSO 1211	98.041	97.640	98.212	1.587	2.313	0.41	-0.17
ISDO 1203	105.68	105.70	105.68	1.141	1.776	-0.02	-0.01

Table 2: ASTM D445, D7279 vs. D7042 – Comparison of results at 40 °C

In-service oil	SVM 3001 D7042 mm²/s	D445 mm²/s	D7279 mm²/s	R (D445) %	R (D7279) %	deviation D7042 to D445 %	deviation D7042 to D7279 %
ISDO 1307	14.740	14.699	14.742	0.285	0.435	-0.28	-0.29
ISDO 1407	10.439	10.446	10.535	0.130	0.416	0.06	-0.86
IDSO 1211	13.640	13.695	13.750	0.104	0.352	0.04	-0.40
ISDO 1203	12.250	12.215	14.276	0.180	0.485	-0.24	-0.36

Table 3: ASTM D445, D7279 vs. D7042 – Comparison of results at 100 °C

ASTM D445 states the reproducibility (R) only for fresh formulated oils, but not for used oils. As an alternative, approach the results (robust mean) from the ASTM proficiency testing program (PTP) were used.

5.2 In-service oil from an engine test bench

The results for the two samples are based on mean values from a series of n = 10 measurements in the method “viscosity index” (single determination at each temperature, cleaning after each finished measurement). The results were compared to reference values obtained for these oils. Additionally, standard deviation and repeatability of the samples were determined.

The reference data was measured with SVM 3001.

5.2.1 Kinematic viscosity

Measurement precision:

Sample	Temp. [°C]	kin visc (measured) [mm²/s; cSt]	Std dev (1 σ) [%]	Repeatability r, 2 σ [%]
In-serv oil No. 1	40	68.860	0.12	0.24
	100	11.955	0.05	0.10
In-serv oil No. 2	40	55.745	0.24	0.48
	100	9.2473	0.06	0.11

Table 4: Kinematic viscosity results and precision data

Deviation to reference data:

Sample	Temp. [°C]	kin visc (measured) [mm²/s; cSt]	Reference [mm²/s; cSt]	Dev to Ref. r, 2 σ [%]
In-serv oil No. 1	40	68.860	69.320	-0.67
	100	11.955	12.004	-0.41
In-serv oil No. 2	40	55.745	55.994	-0.45
	100	9.2473	9.2633	-0.17

Table 5: Kinematic viscosity results vs. reference data

5.2.2 Viscosity Index (VI)

The Viscosity Index was automatically calculated by SVM 3001 from the kinematic viscosity obtained at 40 and 100 °C. This procedure is usually sufficient for in-service oil testing, but does not fulfill the requirements of ASTM D2270, as there are repeat measurements required at both temperatures.

Sample	Viscosity. Index (V) (determ.)	Reference VI	Deviation. to Reference VI [%]
In-serv oil No. 1	171.44	171.17	0.16
In-serv oil No. 2	147.57	147.15	0.29

Table 6: Viscosity Index results vs. reference values

6 Conclusion

SVM x001 is well suited for determining the kinematic viscosity of in-service lubricating oils, provided that all requirements according to section 4 “Measurement of in-service oil” are fulfilled.

Figure 2: SVM 3001 with mounted Magnetic Particle Trap

7 Literature

- DIN 52659-2
- ASTM D7042
- EN ISO 3104
- ASTM D445
- GOST 33-82
- ASTM D2270
- ASTM D7279

Contact Anton Paar GmbH
Tel: +43 316 257-0
support-visco@anton-paar.com
www.anton-paar.com

APPENDIX

Appendix A. In-service oils analysis

The main reasons for in-service oil analysis are:

Assessment of the oil condition to provide information and recommendations for further use in the equipment. To extend the oil change interval is not only a significant cost factor especially for machinery using large quantities of lubricant but also an environmental aspect.

Assessment of the machinery condition to allow the detection of upcoming problems and thus prevention of issues which can lead to damage followed by costly down-times and repair or at least to unreliable operation of machinery.

In-service lube oils can be stressed by combinations of high temperatures, pressure, shear forces, chemical impact, further by particles. All those influences change or destroy their structure.

One of the most important additive group are Viscosity Index improver (VI Improver, VII) respectively viscosity modifiers. In use, the properties of the VI improver become constantly worse, which has significant influence on the viscosity-temperature behavior of the oil. VI improver consist mainly of polymer molecules that are small and coil-shaped when cold. In that state they do not increase the oil‘s viscosity. With rising temperature, the molecules unfold. Consequently, they reduce the decrease of viscosity that is caused by the higher temperatures. For example, excessive shearing at high temperatures destroys the molecules, which results in a decrease of viscosity.

Further, the BN (Base Number, also TBN - Total Base Number) decreases, the oil cannot neutralize sour combustion products. This increases the AN (Acid number, also TBN -Total Acid Number), which leads to more corrosive wear in the machinery. In addition, the ability to keep particles in suspension decreases. Contaminants like soot, ash or sludge drop and can clog oil lines.

Used oil analysis includes many tests, as only a set of parameters allows a statement about the machinery health, the current oil condition and the remaining time the oil can further be used. Kinematic viscosity is a key parameter. Depending on the type of machinery (internal combustion engine, gears, industrial machinery, marine engine, wind power plant ....), oil testing labs offer several test packages including the specific test parameters.

Appendix B. Why measure viscosity?

Oil changes its viscosity over the time of use. Lubrication is essential for all machinery. Changes in the lubricant’s viscosity is not only an indicator for the normal wear of lubricant and equipment but also for possible problems.

Reasons for increase of viscosity:

Soot, low oil level, oxidation, nitration, sulphation, contamination by residual fuel (for engines running on heavy fuel oil), water (coolant, condensate), engine metal debris (metal particles), dust, silicates.

Reasons for decrease of viscosity:

Dilution by fuels, use of lower viscosity lubricating oil for topping up, contamination with cleaning fluids.

Viscosity measurement alone cannot clearly show which problem has occurred. Further tests are required.

Parameters

For in-service oils, kinematic viscosity is measured. Further the viscosity index (VI) is stated.

IC engine oil

Viscosity of in-service oil of internal combustion engines is mostly measured at 100 °C. The measured values are compared to the SAE summer viscosity values (see Table 4). For engines, there are upper and lower caution and critical limits established for the change in kinematic viscosity at 100 °C:

- Upper limits:
  – caution limit +10 % of kinematic viscosity
  – critical limit +20 % of kinematic viscosity
- Lower limits:
  – caution limit -5 % of kinematic viscosity
  – critical limit -10 % of kinematic viscosity

Industrial oil

On the contrary, kinematic viscosity of used industrial oil (ISO class oils) is typically measured at 40 °C except for machinery operated at elevated temperatures. It is compared to the ISO viscosity table and must be within the maximum and minimum of the class (see Table 5).

Kinematic viscosity (low-shear) at 100 °C

While the engine is at operating temperature, the oil has a high temperature. For SAE W-classes (winter classes) a minimum viscosity, for SAE summer classes a viscosity range is specified.

Viscosity Index (VI)

The VI shows the influence of temperature on an oil‘s viscosity. It is calculated from kinematic viscosity at

40°C and 100 °C according to ASTM D2270. ASTM D7042 is referenced in this standard for determination of kinematic viscosity. Low VI means a considerable change of viscosity with change of temperature. Such oil is highly viscous at low temperatures and rather liquid at high temperatures. A high VI means the opposite, a small change of viscosity over a wide temperature range.

SVM 4001 is perfectly suited for VI measurement. It measures kinematic viscosities at 40 °C and 100 °C with repeated determinations and automatically calculates the VI from the obtained results.

SVM 3001 also provides a measurement mode, which automatically calculates the VI. As measurements at 40 °C and 100 °C are only single point determinations, The VI-mode of SVM 3001 is not compliant to ASTM D2270.

For SVM 2001 the VI-mode is optionally available.

Viscosity Tables

IC engine oils

While the engine is at operating temperature, the oil has a high temperature. For SAE W-classes a minimum viscosity, for SAE summer classes a viscosity range is specified. Table 4 shows an excerpt of the SAE J300 viscosity specifications:

SAE Viscosity grade	Low shear rate kinematic viscosity at 100°C [mm²/s, cSt] min.	Low shear rate kinematic viscosity at 100°C [mm²/s, cSt] max.
0W	3.8	
5W	3.8	
10W	4.1	
15W	5.6	
20W	5.6	
25W	9.3	
8	4	6.1
12	5	7.1
16	6.1	8.2
20	5.6	9.3
30	9.3	12.5
40	12.5	16.3
50	12.5	16.3
60	21.9	26.1

Table 7: Crankcase lubricants - viscosity specifications (SAE J300)

Gear Oil viscosities can be found in SAE J306.

Industrial oils, hydraulic oils

All other than engine oils are specified in ISO 3448. This standard knows currently 18 viscosity grades (ISO VG) from 2 mm²/s to 1500 mm²/s. Each grade specifies a center viscosity at 40 °C with tolerable maximum deviations of 10 % in both directions: this specifies an acceptable viscosity range at 40 °C. See Table 5 for the ISO viscosity grades (excerpt of full viscosity specification table).

ISO Viscosity grade	Center point viscosity at 40°C [mm²/s, cSt]	Low shear rate kinematic viscosity at 100°C [mm²/s, cSt]	
		min.	max.
ISO VG 2	2.2	1.98	2.42
ISO VG 3	3.2	2.88	3.52
ISO VG 5	4.6	4.14	5.06
ISO VG 7	6.8	6.12	7.48
ISO VG 10	10	9.0	11.0
ISO VG 15	15	13.5	16.5
ISO VG 22	22	19.8	24.2
ISO VG 32	32	28.8	35.2
ISO VG 46	46	41.4	50.6
ISO VG 68	68	61.2	74.8
ISO VG 100	100	90.0	110
ISO VG 150	150	135	165
ISO VG 220	220	198	242
ISO VG 320	320	288	352
ISO VG 460	460	414	506

Table 8: Viscosity classification of oils according to ISO 3448

Although there are many other oil specification standards, the viscosity specifications are more or less related to SAE J300/J306 or ISO 3448, respectively. Manufacturer standards (OEM standards) and military standards sometimes state more rigorous specification limits.

Appendix C. How to obtain viscosity results on problematic samples

If problems during measurement occur, e.g. no results can be achieved, the following tests may be helpful.

Temperature scan (SVM 3001 only)

Perform a temperature scan to check for the right temperature, at which results in the desired precision class can be achieved.

Select e.g.: Start temperature: 20 °C, stop temperature 100 °C, step: 5 °C.
Precision class: fast, equilibration time: 60 s

SVM 3001 serves additionally to the measured values a graphical evaluation of the scan. Alternatively you can export the measured data and evaluate them on your PC using a spreadsheet program. The graph (here obtained by a spreadsheet program) shows the comparison between an oil which starts gassing at high temperatures and one that does not. For this example, a suitable measuring temperature would be 90 °C instead of 100 °C.

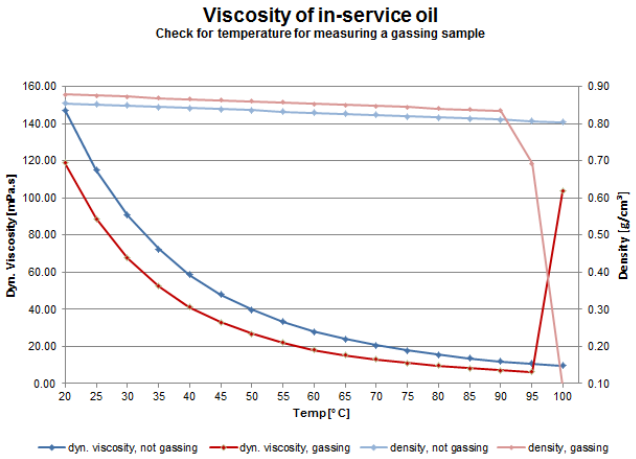


Figure 3: Graph from temperature scan (spreadsheet program)

Time scan (SVM 3001 only)

If a sample does not serve valid results even after sample preparation and even at different temperatures than 40 respectively 100 °C within a reasonable time frame perform a Time Scan. The time scan allows to record a number of data sets and it serves graphic evaluation of these data. Alternatively you can export the measurement results to a USB flash drive and evaluate the data on your PC using a spread sheet program.

Select e.g. for the duration 15 minutes, for the interval 10 seconds. In this case you get a data set every 10 seconds which allows you to check the viscosity behavior of the sample.

You can see if:

- the sample reaches the set precision class and after which time; if not, which precision class can be reached.
- the results show scattering values. - Try to homogenize the sample.
- the viscosity or density values increase or decrease for a longer time until they become stable.
- the viscosity or density values increase or decrease and do not become stable. – Seems that gassing occurs. Try to measure by applying counter pressure.

With this information, you can either set an equilibration time to get anyway results respectively to achieve them in your selected precision class or you can see, that the sample can be measured only with less precision due to its properties.