Viscosity of Metalworking Fluids in Cutting Processes Determined with SVM™ 3001 or SVM™ 4001 Viscometer

Relevant for: machine shops for industrial production, manufacturing workshops, cutting fluid R&D, QC in cutting fluid production

Metalworking fluids are a vital part of manufacturing processes. Viscosity influences the liquid's performance and the manufacturing quality. SVM™ is a fast and precise solution to measure viscosity and density, which are quality relevant parameters.

Figure 1: Cutting fluid – essential for perfect surface quality

1 Introduction

Metal working fluids (MWF) are complex mixtures of base liquids and additives, carefully selected and blended to provide optimum performance in a given application. There are different types: straight oils, oil-based water miscible fluids (emulsions, semi-synthetic fluids), and synthetic fluids.

Metalworking fluids in cutting processes

Water miscible fluids are one main group used in cutting processes such as drilling, milling, or turning, while oils are often used for grinding, honing, or threading. Their main function is to lubricate and cool the contact zone between a machine tool and a work piece. Depending on the combination of work piece and tool, but also on the cutting speed, different fluid compositions are required. Straight oils and oil concentrate are evaluated for viscosity and density, further for pour point, flash point and other parameters. When mixing concentrates with water, the correct dilution ratio can be checked with a refractometer.

2 Why measure viscosity?

Viscosity has considerable influence on the properties of a cutting fluid. Higher viscosity improves the lubrication abilities of the fluid, but decreases the cooling performance. Lower viscosity provides better cooling performance and easier removal of solid particles. On the other hand, this may lead to a lack of lubrication between tool edge and work piece, especially at higher production speed. Poor surface quality and increased tool wear can occur. So viscosity affects the speed, at which the liquid fills the contact zone between cutting tool and work piece, and the thickness of the liquid film. Viscosity measurement helps to find a balance between fastest possible machine parameters and best possible surface quality of the work piece.

The viscosity of cutting oils is typically specified and measured at 40 °C. Some manufacturers test the oil additionally at 100 °C and state the viscosity index. Other test the kinematic viscosity at 100 °F (37.78 °C) or state Saybolt viscosity (SSU – Saybolt Seconds Universal) at 100 °F (and 210 °F). Density is stated at 15 °C or 20 °C.

Which samples are tested?

Two different cutting oils were tested:

Sample name	Sample type
Jokisch Monos Atos N3S (Special cutting oil S91)	Cutting oil, free of mineral oil
Castrol Honilo 980	Cutting fluid, hydrocarbon based, water insoluble

3 Which instruments apply?

The samples were tested with SVM™ 3001. This instrument serves for viscosity measurement according to ASTM D7042 and simultaneous density measurement according to ASTM D4052 (ISO 12185). Additionally, the instrument can determine API density, Saybolt Viscosity and other parameters. SVM™ 3001 also provides temperature and time scans for testing viscosity at different temperatures or over time.

If viscosity index determination according to ASTM D2270 is required, SVM™ 4001 is suitable. It provides two measuring cells for simultaneous measurement with repeated determinations at two different temperatures.

For quality control of kinematic viscosity at a single temperature only without the need of API density, SVM™ 2001 can be used.

SVM™ can test all grades and types of cutting fluids with Newtonian properties.

4 Measurement of cutting fluids

Generally, the procedure is the same as for base oils or lube oils. Refer also to the Anton Paar Application Report "Viscosity of Lube Oils" (Doc. No. D89IA007EN) available on the Anton Paar Extranet.

4.1 Settings

For measurements according to ASTM D7042:

- Method: Standard
- Precision class: Precise
- Automatic repetitions: 5
- RDV limit: 0.10 %
- RDD limit: 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 and to apply the correction, refer to the SVM™ X001 Reference Guide.

4.3 Sample preparation

If the sample is not freshly drawn from a production line or other reservoir, 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

5 mL single-use plastic syringes are recommended. Never use syringes with rubber seals, as the rubber is chemically not resistant to most oils. Further these syringes tend to suck bubbles. For SVM™ 4001, use a 10 mL syringe.

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

Inject approximately 1.5 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 4 to 5 mL for SVM™ 3001. 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) was appropriate for the tested fluids.

Depending on the chemical composition of cutting fluids, other solvents may be required. Some fluids may require an aromatic solvent, as they are not completely soluble in petroleum benzine. In that case, use toluene or xylene as first solvent and an aliphatic hydrocarbon solvent (e.g. *n*-Heptane) as drying solvent.

Others may need an alcoholic component. In this case, a mixture of toluene and isopropyl alcohol can be a suitable solvent.

The typical solvent amount was 6 to 8 mL per sample.

For details, see the SVM™ X001 Reference Guide.

4.5.2 Cleaning procedure

- Tap the cleaning button to open the cleaning screen. Observe it during the cleaning procedure to get information on the cleaning status of the SVM™.
- Remove the sample from the cells (push through using an air-filled syringe).
- Fill approximately 2 mL of solvent using a syringe and leave the syringe connected.
- For sticky or highly viscous oils: 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 several times back and forth (motor at filling speed) to improve the cleaning performance in the cells.

- 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

This report compares results measured with SVM™ 3001 (ASTM D7042) with typical values from the product data sheets of the cutting fluids. The results of SVM™ 3001 are mean values obtained from a series (n = 12) of repeat measurements (cleaning in between the valid results).

There are no specific standards available for cutting fluids. The viscosity specifications of industrial oils are more or less related to ISO 3448, which states a tolerance of ± 10 % to the specified kinematic viscosity at 40 °C. Manufacturer standards (OEM standards) may state more rigorous limits.

ASTM D 7042 (and either ASTM D445) do not state any data for precision and bias of cutting fluids.

Viscosity at 40 °C

Sample	Meas. kin. visc. [mm²/s; cSt]	Typical kin. visc. [mm²/s; cSt]	Dev. [%]	Within ISO 3448 range
N3S (S91)	31.75	30	5.83	OK
Honilo 980	4.281	4.5	-4.87	OK

Table 1: Kinematic viscosity and deviation to typical values

Precision data of viscosity measurement:

Sample	Standard deviation [%]	Repeatability (r; 2 σ) [%]
N3S (S91)	0.07	0.14
Honilo 980	0.02	0.04

Table 2: Standard deviation and repeatability of the measured oils

Density

Measured density at 40 °C

Sample	Density [g/cm³]	Std. deviation [g/cm³]	Repeatability (r; 2 σ) [g/cm³]
N3S (S91)	0.9060	0.00005	0.00009
Honilo 980	0.8083	0.00003	0.00005

Table 3: Density, measured results and precision data

N3S (S91) oil - API density at 20 °

Determined API density [g/cm³]	Typical value (Data sheet) [g/cm³]	Dev. to typical value [g/cm³]
0.9187	0.9	0.0187

Table 4: Jokisch N3S (S91) – determ. API density vs. typical value

Honilo 980 oil - API density at 15 °

Determined API density [g/cm³]	Typical value (Data sheet) [g/cm³]	Dev. to typical value [g/cm³]
824.11	824	0.11

Table 5: Castrol Honilo 980 – determ. API density vs. typical value

6 Conclusion

SVM™ 3001 is perfectly suited for determining the viscosity of cutting fluids, provided that all requirements according to section 4 "Measurement of cutting fluids" are fulfilled.

Figure 2: SVM™ 3001 and SVM™ 4001

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7 Literature

- Anton Paar Application Report: "Viscosity of lube oils" (Doc. No. D89IA007EN)
- ASTM D7042: Standard Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer™ (and the Calculation of Kinematic Viscosity)
- EN ISO 3104: Petroleum products - Transparent and opaque liquids - Determination of kinematic viscosity and calculation of dynamic viscosity
- ASTM D445: Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)
- ISO 3448: Industrial liquid lubricants – ISO viscosity classification

APPENDIX

Appendix A. About cutting fluids

Cutting is a chip-removing metalworking process using tools to shape a work piece. Main processes are e.g. turning, drilling, milling, grinding, or honing.

Fluid types

Cutting fluids can be:

- Straight oils, which can be mineral oils, synthetic, vegetable, or animal oils. They provide very good lubricity properties, but are not designed for high machining speeds. They consist mainly of a base oil with additives.
- Emulsions, which are soluble oils mixed with water and other additives like corrosion protectors, surfactants, pH regulators, wear protectors, and biocides. Such emulsions contain only a low percentage of the concentrate, the main component is water. They have less lubrication properties and their main field is cooling. They are suited for high machining speeds, where the working zone is flooded with the liquid.
- Semi-synthetic fluids containing small amounts of oil plus additives. They provide lower lubricity than oils, but high cooling performance.
- Synthetic fluids, which are blended from different coolants, containing no oil. They are designed to provide the properties of all other cutting fluids. They have high cooling performance, but not equally good lubricity as oils, produce no smoke, provide low surface tension and thus quick wetting properties. They are mainly used in high-speed turning of hard materials and for grinding processes.

Importance of viscosity

Viscosity is important for:

- Cutting oils, synthetic and semi-synthetic fluids. Further for concentrates before mixing them with water.
- Selection of the appropriate size and type of the fluid application system (pumps and nozzles).
- The design of bulk storage and delivery system for cutting oils, coolant concentrates and other compounds.

Manufacturers state viscosity and density in various notations in their data sheets:

- Kinematic viscosity at 40 °C, 100 °F (37.78 °C), sometimes at 100 °C, sometimes with VI
- Dynamic viscosity at 25 °C
- Saybolt Universal Seconds (SUS; SSU)
- Density at 15 °C or 20 °C
- Specific gravity at 20 °C or 25 °C

All these parameters can be determined using the suitable instrument of the SVM™ X001 series.

Water diluted liquids (emulsions) have a low viscosity close to water and are normally not viscosity tested. However, the measuring results in Table 6 give an idea for the viscosity and density values of of an emulsion.

Measured at 20 °C

Sample	Kin. Vis. [mm²/s]	r; (2 σ) [%]	Density [g/cm³]	r; (2 σ) [g/cm³]
Hi-Speed 415 (approx. conc. 5 %)	1.374	0.9	1.0002	0.00017

Table 6: Kinematic viscosity and density of a cutting emulsion

Cutting fluid monitoring

To extend the service lifetime of cutting fluids, they need to be checked regularly. Although contamination and degradation of the liquid also have effects on the viscosity, this parameter usually is not monitored.

To check the concentration of the cutting fluid, refractometers are used.

The content of tramp oil (unwanted lube oil which has leaked into the cutting fluid system) is analyzed by titration.

Further pH-level and alkalinity are tested.