

1 Emissions when using minimum quantity lubrication (MQL)

Within the scope of a joint project of the former Süddeutsche Metall-Berufsgenossenschaft in cooperation with lubricant manufacturers and industrial companies, the emissions during metalworking with MQL were investigated [3]. Furthermore, measures for reducing emissions during minimum quantity lubrication were developed as a guidance for drawing up a risk assessment. These measures are described below.

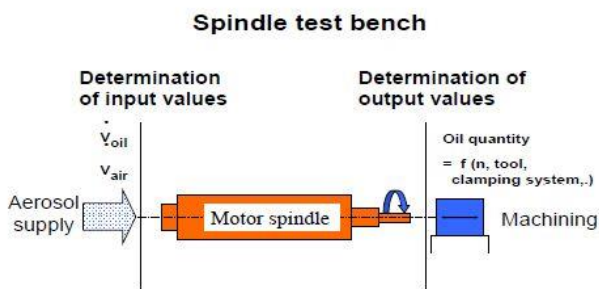


Figure 2 – Systematic layout of the spindle test bench

1.1 Laboratory tests

During the first phase of the project, the selected lubricants for minimum quantity lubrication were heated (pyrolysed) to 400°C and 800°C in synthetic air in the laboratory (IFA) and the volatile constituents were analysed [4]. The pyrolysis tests served to determine the quality of hazardous substances that might occur as a result of thermal load of the lubricants during machining in the tool/chip area.

During the pyrolysis tests of the lubricants used in the laboratory, traces of saturated and unsaturated hydrocarbons, aldehydes and ketones, saturated and unsaturated esters (C 16 - C 25) as well as higher-value alcohols (> C 15) were identified. However, the concentration of the identified pyrolysis products could be classified as very low in all tests.

1.2 Machining tests on the spindle test bench

Machining tests using minimum quantity lubrication with internal supply were carried out on a test bench at the Fraunhofer Institute for Chemical Technology. The core component of the test bench was a high-speed cutting (HSC) motor spindle with an internal aerosol channel, a single-axis traversing table for cutting tests and a force measuring platform for recording the cutting forces (Fig. 1, 2).

The drilling method was selected for the machining tests. The tests were carried out under practical conditions, with varying cutting parameters and materials (steel, aluminium and cast materials). For this purpose, special twist drills for dry machining with two internal cooling channels were used (Figure 3).

Two groups of lubricants were tested. The first group consisted of pure synthetic ester oils of different viscosities with favourable tribological properties and a high thermal load capacity. The second group consisted of different finished lubricant products which are already applied in practice.

The emission tendency of different lubricants could be determined and compared under reproducible conditions during machining inside the test bench enclosure, directly at the point of origin.



Figure 3 – Applied twist drills for dry machining in the front view

1.2.1 Emissions during drilling

The oil aerosol and oil vapour emissions for the ester oils measured over a period of 15 minutes under practical conditions (feed rate: $F_r = 800$ mm/min) are listed below (Figure 4).

During the machining tests, a strong mist formation was observed, especially with the low viscosity lubricants (< 10 mm²/s at 40°C). The high-viscosity esters with a viscosity greater than 20 mm²/s at 40°C, however, showed significantly lower emission values.

MWF emissions; $F_r = 800$ mm/min; Jel Drill

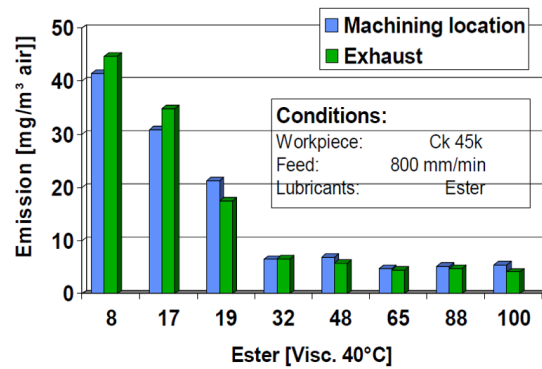


Figure 4 – Oil aerosol and oil vapour emissions at the cutting zone

MWF emissions; $F_r = 200$ mm/min – 800 mm; Jel drill

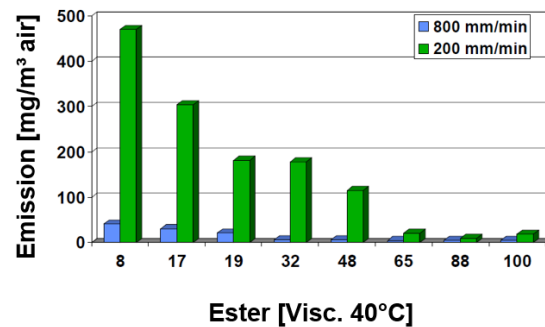


Figure 5 – Emission values of oil aerosol and oil vapour at reduced feed rate

The influence of the cutting parameters on the emission behaviour of the lubricants is shown in Figure 5, by the example of two selected feed rates. The feed rate was reduced from 800 mm/min (standard) to 200 mm/min (extremely unfavourable) at constant cutting speed.

Machining with very unfavourable cutting parameters results in a sharp rise of the oil vapour and oil aerosol emissions. The reason for this is the high dwell time of the drill at a low feed rate combined with an increased thermal load on the lubricant.

Figure 6 shows how decisive the selection of suitable lubricants and the optimal machining parameters are for low-emission MQL machining.

Ester 8: Aerosol + vapour $F_r = 200, 800, 1000$ mm/min

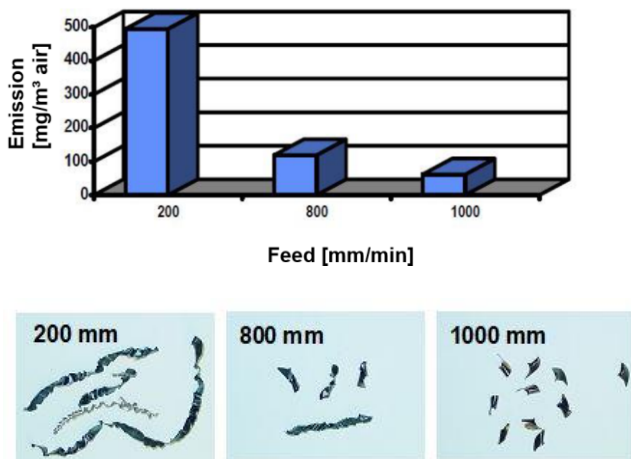


Figure 6 –Variation of feed rate when applying the lubricant ester 8 with resulting chip shape

Machining with optimal working conditions owing to high feed rates results in short friable chips, high cutting performance, long tool life and, at the same time, the lowest emissions. Unfavourable cutting conditions, on the other hand (due to tests with reduced feed rates), lead to high emissions with simultaneously unfavourable machining conditions (due to long chips and high tool wear).

Recently, there has been an increasing tendency to use very low viscosity media with a low flash point ($< 100^\circ\text{C}$), which should evaporate as residue-free as possible after machining. In order to assess the emission behaviour of these lubricants, a sample with very low viscosity ($3 \text{ mm}^2/\text{s}$ at 40°C) was tested in comparison. The result of these tests is shown in Figure 7.

The emissions measured for the low-viscosity oil exceed the values of the conventional products many times over. This clearly shows how negatively low-viscosity products can affect the overall situation at the workplace due to their very high emissions, especially because of the high vapour content. High-viscosity products should therefore be preferred.

MWF emissions; $F_r = 1000$ mm/min; drill KMH

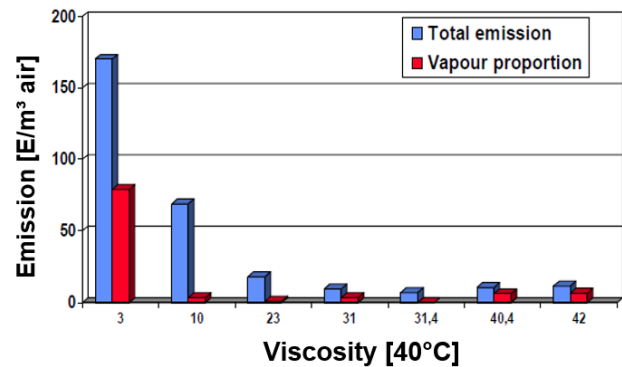


Figure 7 – MWF emissions finished products; feed rate: 1000 mm/min

1.2.2 Pyrolysis products during drilling

Under practical cutting conditions, only minimal concentrations of pyrolysis products were detected. Slightly higher values were measured when the lubricant was subjected to high thermal loads ("worst case" scenario due to incorrect operation, malfunction). In this case as well, the high-viscosity media showed a significantly lower tendency to pyrolysis than the thin-bodied, low-viscosity lubricants. However, even in the immediate vicinity of the point of origin, the measured concentrations are in a range $0.1 \text{ mg}/\text{m}^3$ at maximum and are thus to be regarded as uncritical.

In summary, it can be stated that very low concentrations of pyrolysis products were measured for all tested lubricants, even under extreme conditions with high thermal load in the test bench. The tendency to form pyrolysis products in minimum quantity lubrication can therefore be classified as very low.

1.3 Exposure measurements in practice

As part of a special measurement programme, exposure measurements were carried out at workplaces with MQL processing on machine tools in production. During these assessments, measurements were taken on the operator, stationary at the control panel of the machine and inside the machine (Figures 8, 9).

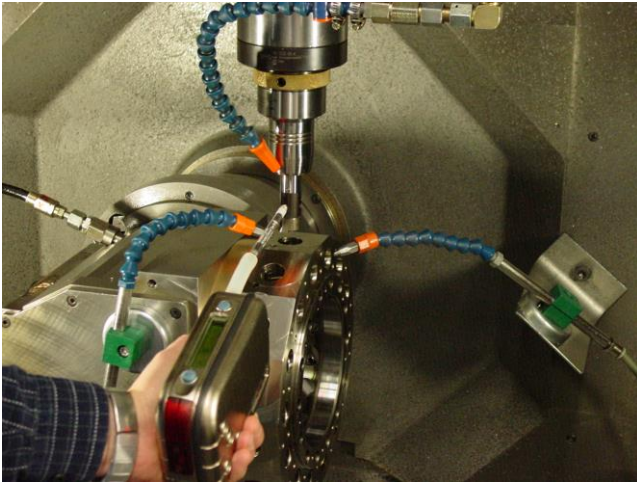


Figure 8 – Determination of CO concentration with direct-reading measuring device

When materials are machined with minimum quantity lubrication on machine tools during production, metalworking fluid vapour and aerosols have emerged to be the exposure-determining components. Aldehydes (formaldehyde) were only detected in traces ($\ll 1\%$ of the former air limit value) in individual cases.



Figure 9 – Exposure measurements taken on the operator and stationary at the control panel

A total of 16 comprehensive measurement series were carried out in working areas in practice. In none of the cases, the air limit values were exceeded. The measured concentrations in the working area were so low that for a total of 11 cases the result was "Continuously safe compliance with the former air limit value" and for five cases "Compliance with the air limit value".

Half of the measured values were significantly below 15 % of the former air limit value for metalworking fluids, at 1.4 mg/m^3 . In 95 % of the cases, half of the limit value of 5 mg/m^3 was not exceeded.

1.4 Summary

All investigations and findings have shown that the reasonable use of minimum quantity lubrication allows low-emission metalworking with a reduction of skin-damaging potential.

However, this requires an overall assessment of the system. Reliable machining is achieved when the elements lubricant, tool, metering device and machine are suitable for minimum quantity lubrication and adapted to each other in the best possible way.

A detailed description of further results and information on MQL machining can be found in the project report "Gefährdungsbeurteilung bei der Trockenbearbeitung metallischer Werkstoffe". The project report and the DGUV Information 213-723 723 „BG/BGIA Empfehlungen für die Gefährdungsbeurteilung nach der Gefahrstoffverordnung – Minimalmengenschmierung bei der Metallzerspannung“ [5] are available for download on the Internet at www.dguv.de.

2 Information on low-emission metalworking with MQL

DGUV Information 213-723 723 „BG/BGIA Empfehlungen für die Gefährdungsbeurteilung nach der Gefahrstoffverordnung – Minimalmengenschmierung bei der Metallzerspannung“ specifies the criteria for compliance with the air limit values in the work area. Control measurements according to TRGS 402 [6] can be dispensed with if the following conditions are met:

2.1 Selection of lubricants

The proper **selection of the lubricant** is of decisive importance for low-emission metalworking with MQL. To minimize emissions, lubricants with toxicological and dermatological suitability, with the best possible lubricating properties and high thermal load capacity should be used. Synthetic ester oils and fatty alcohols with low evaporation properties, toxicological suitability and a high flash point have proved to be particularly effective in practice [7], [8].

The **flash point** (DIN EN ISO 2592) [9] and the **Noack evaporation loss at 250°C** (DIN 51581-1) [10] have proved to be particularly useful as guide values for selecting a low-emission lubricant. The lubricant should have a flash point of at least 150°C, a maximum evaporation loss of 65% at 250°C and a viscosity of > 10 mm²/s at 40°C (DIN 51562-1) [11].

Viscosity at 40°C DIN 51562-1	Flashpoint open cup DIN EN ISO 2592	Noack evaporation loss at 250°C DIN 51581-1
[mm ² /s]	[°C]	[%]
> 10	> 150	< 65

Table 1 –Guide values for the selection of a low-emission lubricant

The following substances are rather not recommended for minimum quantity lubrication:

- Water-miscible metalworking fluids and their concentrates
- Lubricants with organic additives containing chlorine or zinc
- Lubricants that require labelling in accordance with the Ordinance on Hazardous Substances
- Products based on mineral base oils in the metalworking fluid > 3 ppm benzopyrene
- Native esters (rapeseed oil) with a tendency to gumming on aggregates, guides and ageing/gumming due to low oxidation and hydrolysis stability

- Ethanol (also called methylated spirits or ethyl alcohol).

2.2 Requirements for metering systems

The assurance of continuous lubricant supply to the operating point, without interruption, is of particular importance for process safety and emission. Therefore, only safe systems that meet the following requirements are to be used for the supply and dosing of the lubricant:

- Parameters (e.g., quantity and pressure) can be set according to predefined values depending on the process, the material and the machining parameters.
- Precise and vibration-insensitive alignment of the nozzle(s) relative to the operating point is possible.
- Monitoring of the MQL function (e.g. filling level, media transport and compressed air) is possible.
- Spraying characteristics of the nozzle:
 - Indication of favourable system setting parameters to minimize mist formation
 - Targeted wetting (specification of the effective ranges of the nozzle)
- Indication of viscosity range that can be used in the system at 40° C
- Loss-free media transport to the nozzle or tool transfer point is ensured (no leaks).
- Components and seals resistant to the media used in accordance with the application
- Smallest setting possible for implementing dry workpieces and chips (scaling < 10 ml/h).
- Continuous supply of the lubricant medium ensured (no interruptions).
- Fast response properties and media availability at the cutting point, even during longer downtimes.
- Low noise development during operation (<75 dB [A])

2.3 Requirements for the tools

The selection of the appropriate tool is of decisive importance as a basis for trouble-free, reliable metalworking [12]. Therefore, suitable

tools approved by the manufacturer should be used for minimum quantity lubrication. The cutting parameters (rotational speed, cutting speed, feed rate) specified by the tool manufacturer must be observed.

2.4 Skin protection

The use of minimum quantity lubrication reduces the potential for skin damage compared to conventional wet machining.

If direct skin contact with metalworking fluids cannot be avoided, appropriate skin protection measures must be taken:

- Prepare a skin protection plan (skin protection plan B for non-water miscible metalworking fluids according to DGUV Information 209-022) [13].
- Avoid skin contact by using auxiliary tools.
- Protect endangered skin areas by protective clothing (DGUV Regulation 112-189 [14]).
- Unless working on rotating machinery, use durable protective gloves (DGUV Regulation 112-195 [15]).
- Provide skin protection, skin cleansing and skin care products (DGUV Information 212-017 [16], DGUV Information 209-022, DGUV Rule 109-003) [17].
- Train employees in the use of skin protection products.

3 Summary and limits of application

This Fachbereich AKTUELL is based on experience and knowledge gathered by the Expert Committee Woodworking and Metalworking (FB HM), Subcommittee Machinery, Robotics and Automation of DGUV (German Social Accident Insurance on emissions occurring during the use of minimum quantity lubrication during metal cutting.

The provisions according to individual laws and regulations remain unaffected by this Fachbereich AKTUELL. The requirements of the statutory regulations apply without restriction.

In order to obtain detailed information, it is necessary to consult the applicable regulation contents.

This „Fachbereich AKTUELL replaces the same-titled version, published as DGUV Information sheet No. 006, issue 07/2005). Updating was required as a result of editorial adjustments. This is the English translation of the German issue “FBHM-006” of 13 August 2021.

The Expert Committee Woodworking and Metalworking is composed among others of representatives of the German Social Accident Insurance Institutions, federal authorities, social partners, manufacturers and users.

Further „Fachbereich AKTUELL“ or Information sheets of the Expert Committee Woodworking and Metalworking are available for download on the Internet [18].

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- [18] Internet: www.dguv.de/fb-holzundmetall, Publikationen oder www.bghm.de Webcode: <626>
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The pictures shown in this „Fachbereich AKTUELL“

Figure 1 – Spindle test bench with HSC-motor spindle for internal aerosol supply

Figure 2 – Systematic layout of the spindle test bench

Figure 3 – Applied twist drills for dry machining in the front view

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Figure 7 – MWF emissions finished products; feed rate: 1000 mm/min

Figure 8 – Determination of CO concentration with direct-reading measuring device

Figure 9 – Exposure measurements taken on the operator and stationary at the control panel

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Table reference:

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